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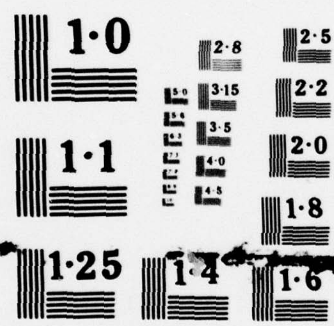

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DEVELOPMENT OF A TECHNICAL PRACTICE FOR RUDDERS AND DIVING PLANES.

PART II.
TORQUE PREDICTIONS,

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*Appendixes G & H were originally contained in Part I of this Technical Practice (NAVSEC Report 6136-74-271) as appendixes D & E.

1. INTRODUCTION

The purpose of the subject task is to develop a technical practice for calculating the rudder and diving plane torque requirements. In the course of this development, the current NAVSEC procedure for estimating the torque requirements was updated and documented; the current state of the art was defined to determine if the current procedure should be revised; and recommendations were made for future research and development to fill gaps in the current technology.

The scope of this study is restricted to the force and torque calculation procedure for rudders and diving planes, although it is realized that this is only a part of the larger problem of predicting ship maneuverability. The study of ship hull maneuvering characteristics and the proper selection of control surface area, location and shape and other parameters which affect the torque requirements, were covered very briefly in this report.

Section 2 of this report contains a general discussion of control surface design considerations which should be made in their selection and construction. These considerations are discussed in order to present the overall scope of the control surface design problem, although the subject task only deals with the items outlined above.

Section 3 provides a description of the current method used by NAVSEC for determining the torque requirements of surface ship spade and horn rudders and submarine stern planes,

rudders and fairwater planes. The method assumes the pertinent control surface design considerations have already been addressed. Detailed manual calculation for the current method are provided in the Appendix in a step-by-step fashion.

Section 4 contains the updated sections of the NAVSEC Technical Practices Manual which are pertinent to the subject task. This has been done to present the current practice used by NAVSEC for control surface torque calculations. The sections updated are Section 3 of Part A "Rudder Design", and Sections 3.4, 4.2, 5.1 and 7.1 of Part B "Submarine Control Surfaces. The material of other sections of the Technical Practices Manual related to rudder design are discussed in general terms in Section 2 of this report.

Section 5 presents the state of the art of control surface torque calculations. The material in this section is based on a literature survey. The complete problem of ship maneuverability and its relationship to control surface torque prediction is considered here.

The sixth and final section presents our recommendations for possible revision of the current procedure and for future research and development based on the survey and interpretation of available literature.

We decided not to revise the current procedure for calculating the control surface torque requirements although we do recommend modifying the NAVSEC computer programs to properly reflect the updated procedure outlined herein.

2. CONTROL SURFACE DESIGN CONSIDERATIONS

2.1 Introduction

This section briefly presents a general discussion of considerations necessary for the selection and construction of control surfaces. Although much of this material appears in NAVSEC's Technical Practices Manual, this section does not attempt to describe NAVSEC's design practice for control surfaces.

2.2 Surface Ship Rudder Design

2.2.1 General

The aim of rudder design is to provide tight turning, directional stability, good ability to initiate and check swings rapidly and good course-keeping ability. Quantitative measures of these are usually investigated by tactical diameter, Kempf or Z maneuver (zig-zags) and spiral maneuver (Dieudonné) model tests.

2.2.2 Rudder Planform and Location

Rudder area is chiefly determined by the requirement for tactical diameter, directional stability, and maneuverability while the vessel is undergoing replenishment at sea. With this in mind, the rudder area is proportioned upon length and draft from similar previous ships. Model tests are usually run to verify the directional stability and turning characteristics.

Rudders are generally moved out of a position directly in line with propeller shafting in order to avoid the propeller tail cone vortex. This is even done wherever possible for single screw ships with high power. However, the rudder is always placed partially in the propeller race.

Adequate clearance should be provided so the propeller may be unshipped without unshipping the rudder.

To avoid vibration the minimum distance allowed between the leading edge of the rudder and a point on the line of maximum propeller blade thickness, 0.7 radius from the shaft centerline should equal one-half the propeller diameter.

2.2.3 Rudder Sections

Rudder section shape is defined by the NACA symmetrical four-digit series with thickness/chord ratios dependent on stock size and selected rudder profile. The maximum thickness/chord ratio = 0.23. Normally the maximum rudder swing permitted is limited to 35 degrees with an additional two degrees to hard stop. The after edge has a definite half-breadth and the corners of the trailing edge are left sharp.

2.2.4 Rudder Stock Stress Analysis

A stress analysis is usually made during design and the shipbuilder is usually required to make one based on actual scantlings. Stresses are limited so as to provide a minimum factor of safety of 2.0 on yield with loads computed as indicated in Section 3.2. Where loads are estimated by less reliable means (e.g. Joessel's formula), the minimum factor of safety is taken as 2.5 on yield.

When a roller bearing is used, the rudder stock bending stress will be higher than the stress for a sleeve bearing due to the increase in bending moment resulting from the distance between the ship shell and bearing for maintenance.

2.2.5 Rudder Stock Material

The minimum yield strength for low carbon alloy steel rudder stocks of auxiliary ships is 65,000 psi and for combatant ships 100,000 psi. Where rudder stocks are required to have little or no magnetic permeability, aluminum bronze has worked well on AMS 60 and MSO 421 and MSO 523 classes.

The use of higher strength steels tends to save weight and permit thinner rudder sections both of which are desirable especially if there is difficulty obtaining a chord/thickness ratio of 0.23. There are however the following drawbacks.

(a) The deflection of the stock tends to be greater, involving a potential problem with seals.

(b) The natural frequency tends to be lower which will increase the possibility of vibration.

2.2.6 Rudder Plating and Framing

Rudder plating is HY 80 and internal members are HTS or MS.

2.2.7 Bearings

The two basic types of bearings which are used are

(1) Rolling friction or anti-friction.

(2) Sliding friction or sleeve.

The friction coefficients used are 0.01 for anti-friction and 0.20 for sleeve types. For roller or ball bearings, the ratio of the bearing diameter d_1 to the stock diameter $d = d_1/d = 1.29$.

The bearing material is usually laminated phenolic although cobalt base alloy may be used to permit higher bending stresses.

2.2.8 Bearing Seals and Lubrication

Sleeve and roller bearings within the hull are usually pressure grease lubricated. Adjustable seals are provided and made in halves to facilitate shipping and unshipping.

The most recent practice with roller bearing seals is to use a gland with packing, adjustable from inside the ship for the hull seal. This means moving the hull roller bearing upwards a little with a slight increase in rudder stock bending moment. This seal design has the advantage of being repaired when the ship is afloat.

2.3 Submarine Control Surface Design

2.3.1 General

The basic intent of submarine control surface design is to obtain positive directional stability,

good depth and course keeping ability and good ability to initiate and check trajectory changes. The preliminary design estimate of required control surfaces are generally tested by NSRDC and adjustments made as necessary.

Directional stability and control are basic design requirements for ahead submerged operation. Astern operation is quite unstable and generally whatever comes out of the design that has been based on ahead operation is accepted.

2.3.2 <u>Fairwater Plane Design</u>

Fairwater planes are more commonly called for than bow planes in current design practice.

Fairwater planes outreach is usually kept within the maximum beam to allow for rolling alongside a dock. The height of the planes is important in relation to avoiding difficulties in periscope-depth control. Positioning the planes too high on the sail may cause loss of plane effectiveness.

The leading edge is usually raked to deflect mine cables. Tips should be rounded to reduce noise levels.

2.3.3 <u>Stern Planes and Stabilizers</u>

The area needed at the stern for stability in the vertical plane is determined by theory and model test. The area is usually too large to be all moveable so part of it is installed as a fixed stabilizer.

The planform and location of stern plane and stabilizer are selected with the following considerations in addition to conventional hydrodynamic efficiency:

a) The leading edge rake should be such as to deflect mine cables; for non-rake or very small rake, cable guards should be provided.

b) A minimum distance equal to one propeller radius should be maintained between a point on the line of maximum blade thickness, 0.7 radius from the shaft centerline to the nearest edge of the stern plane.

c) The span, which usually exceeds the beam, should be limited so as to facilitate nesting, coming alongside a dock, and for larger subs to increase the availability of the number of drydocks and building ways that may be employed.

2.3.4 Rudders

The problems associated with submarine rudders are generally similar to those encountered with surface ships. One special problem associated with the topside rudder of a submarine is the flow disturbance caused by the sail and superstructure. Because of this wake disturbance the topside rudder is not very effective for stability where small angles are involved even though quite effective for turning.

The rudder plating is generally HY80 steel with HTS or MS for interior material. Wood with hot vegetable pitch or foamed-in-place plastic syntactic foam may be used as filling material.

2.3.5 Bearings

Departures from practice listed for surface ships as follows:

a) Laminated phenolic bearings are not commonly used on submarines.

b) Anti-friction (roller) bearings are not used for radial loads.

Cobalt base alloy is the usual material for radial loading.

c) Rudder carrier bearings take thrust in a free-flooding space. Nickel-copper-silicon alloy is the most common material for these bearings.

3. CURRENT CALCULATION PROCEDURE FOR RUDDERS AND DIVING PLANES FORCES, TORQUES AND MOMENTS

3.1 Introduction for Calculation Procedure

This section of the report describes the rudder design work after the rudder configuration and location have been determined. The hydrodynamic torque is calculated and from this the structural and mechanical features are determined for reliability at low cost.

In the computation of rudder forces, bending moments and torques, aerodynamic and hydrodynamic methods are used with allowances developed from experience. This procedure will be explained for various types of surface ship and submarine control surfaces.

3.2 Flow Speed and Angle of Attack

3.2.1 Flow Speed

The ship speed used is the speed the ship would attain at full-power plus one knot, with the ship in a light-displacement clean-bottom condition such as can occur on builders trials. Any reduction of speed in a turn is an additional factor of safety and is not calculated. For a rudder in the propeller race the speed of the water over the rudder is assumed to be (Ship Speed as defined above) (1 + Real Propeller Slip). This speed is assumed to occur uniformly over the complete control surface span. For portions of rudders not in the race, ship speed is used.

3.2.2 Angle of Attack

For both surface ship and submarine control surfaces the effective attack angle should be taken as some factor times the actual geometric angle. This is an arbitrary drift angle allowance based on ship trial experience. The factors for various control surfaces are listed in the table below.

Factors Used to Obtain Effective Attack Angle

Control Surface	Factor
Surface Ship Rudder	0.75
Submarine Rudder	5/7
Submarine Stern Plane	1.0
Submarine Fairwater Plane	1.0

3.3 Hull Gap and Effective Aspect Ratio

In order to use free stream aerodynamic and hydrodynamic data, it is necessary to calculate the effective rudder aspect ratio. In ideal cases this is equal to span squared over area and is doubled if there is "no gap" between the rudder root and hull. If the hull gap is small at zero rudder and large at full rudder, the effective aspect ratio is computed

by multiplying the geometric aspect ratio by a coefficient varying linearly from 2.0 at 0 degree to 1.0 at full rudder angle. If the gap is large at all angles, the geometric aspect ratio is used throughout the range of rudder angles.

3.4 Use of Wind Tunnel Data

The calculation of rudder forces and torques is mostly by aerodynamic methods with some modification for ship application. The calculation procedure for Q_H, the hydrodynamic torque, of each of the control surfaces is described below. With the exception of the horn rudder, computer programs exist which can perform these torque calculations.

3.4.1 Spade Rudders

The most important source of data for the torque calculations of spade rudders is DTMB Report 933 "Free-Stream Characteristics of a Family of Low-Aspect-Ratio All Moveable Control Surfaces for Application to Ship Design" (Revised Edition). The data from DTMB Report 933 has been crossfaired so that the ordinary coefficients (lift, drag, normal force, chordwise and spanwise center of pressure) are plotted versus aspect ratio for various angles of attack. This is done for both squared and rounded tip shapes and for sweep-back angles of -8.0, 0.0, and 11.0 degrees. The rudder torque obtained with this method is called Q_H, the hydrodynamic torque. The results of the torque calculation are presented in a plot of Q_H versus attack angle where negative torque indicates a trailing tendency (center of pressure aft of the centerline of the stock).

A detailed example calculation for spade rudders is shown in Appendix A. The basic procedure is as follows:

(A) Use the design charts from the DTMB #933 for the appropriate sweep angle and tip shape and determine the coefficients for lift C_L, drag C_D and chordwise center of pressure $(CP)_c$ for the desired aspect ratio and angle of attack.

(B) Interpolate the coefficients from step (A) between these -8.0,0 and 11 degree values for the values at the actual quarter-chord sweep angle. Sweepback angles higher than 11 degrees can be interpolated using references 6 or 7.

(C) If the taper ratio (defined as tip chord/root chord) differs from the 0.45 values of Report 933 a taper ratio correction must be made. This correction is shown in Appendix B.

(D) Add friction and steering allowance torques to produce the final torque envelope. See Section 3.5.1.

The computer program called Rudder Fairwater Plane Design No. 0305 uses the data from DTMB Report 933 to perform the torque calculation above.

3.4.2. Horn Rudders

For semi-balanced rudders on a horn, the calculation procedure described in DTMB Report 915 is used for the determination of the normal force and center of pressure.

Evaluation of a considerable amount of model and full scale rudder torque test data indicated that the height to chord ratio of each portion of the rudder is the most significant parameter. Other parameters such as section, aspect ratio, thickness and percent balance or hull effects such as wake, drift angle and reduction in speed are assumed to be implicitly taken into account in the analysis. The rudder is considered as two separate portions and the normal force and center of pressure curves may be obtained from empirical curves for each portion. A detailed example calculation for horn rudders is shown in Appendix C.

The basic calculation procedure for predicting the torque of horn rudders is as follows:

(A) Determine the height to chord ratios for the upper and lower portions of the rudder.

(B) Obtain coefficients for the normal force and center of pressure for various rudder angles using the graphs of Report 915.

(C) Determine the moment arm and normal force for each rudder portion.

(D) Determine the torque for each portion of the rudder.

(E) Sum up the torque values of (D) to yield the total hydrodynamic torque Q_H.

(F) Add frictional torque (and torque allowance) to obtain final design torque. (See Section 3.5.1)

3.4.3 Stern Plane with Stabilizers

A detailed example calculation for stern planes with stabilizers is shown in Appendix D. The most important data for this calculation is the NACA WR-L series. The basic procedure is as follows:

(A) Determine the effective aspect ratio by doubling the geometric aspect ratio. If the stern plane has a vertical stabilizer fin at the tips, then a correction must be made to the effective aspect ratio using figure 2 of Appendix D.

(B) Using the taper ratio λ find the angle of attack (crossflow) ratio $(\varepsilon/\varepsilon_{ell})$ from figure 3 Appendix D. This is done for various sections along the span Y/(b/2), where y is the distance along the span starting from the root chord and b is twice the span of the foil.

(C) Obtain the lift slope $C_{\ell\alpha}$ for the aspect ratio from step (A) using EB division design charts A-1407 and A-1409. Obtain the lift slope $C_{\ell\alpha}$ for an infinite aspect ratio.

(D) Using NACA flapped airfoil data, the lift slopes C_L/ϵ are computed for 15, 35 and 50 percent balance flaps. Using these slopes, the lift coefficients C_L may be found.

(E) Using the results from step (D) the hinge moment coefficients C_{hf} may be found for the three balanced flaps.

(F) Correct the lift and hinge moment coefficients for the actual chord length along the span. A new flap chord to mean chord ratio is calculated.

(G) Determine constants $K_1 = \frac{\alpha\delta}{\alpha\delta_{.30}}$. $(\alpha\delta)$ is defined as the partial of the attack angle divided by the partial of the flap angle) and $K_2 = C_{hf\delta}/C_{hf\delta_{c.30}}$ by using figures 7 and 8.

(H) Integrate the sections to obtain the average lift and hinge moment coefficient for the entire span, using the K constants from step (G) and the lift and hinge moment coefficients from step (D) and (E) for each section along the span.

(I) Determine the streamline curvature correction to the average hinge moment coefficient, using the data from figure 9 Appendix D.

(J) Plot values of lift and hinge moment coefficients, which have been calculated for 15, 35 and 50 percent balance versus the ratio of the chord of the fixed plane to the chord of the flap (C_b/C_f). Using the correct chord ratio, the desired lift and hinge moment coefficients are taken from the curves.

(K) Calculate the lift using the value of the lift coefficient from step (J).

(L) Calculate the hydrodynamic torque Q_H using the hinge moment coefficient from step (J).

(M) Determine the normal force coefficient C_{Nf} using figure 13 Appendix D and using this coefficient calculate the normal force.

(N) Add friction and error (6% of flap chord) allowance torques to produce the final torque envelope. See section 3.5.3.

The calculation of forces and torques may be performed by the computer program titled Stern Plan Calculation No. 0218.

3.4.4 Fairwater Planes

In computing forces and centers of pressure, the calculation procedure for fairwater planes is the same as the procedure for spade rudders (section 3.4.1).

3.5 Steering Gear Torque

Going from hydrodynamic torque Q_H and friction torque Q_f to steering gear torque (at the tiller), involves additional allowances. These allowances are ~~discussed~~ are discussed below for each of the control surfaces.

3.5.1 Surface Ship Rudder

A) The first is an error allowance for chordwise center of pressure. This allowance is generally $\pm$ 3 percent of the mean chord. This allowance multiplied by the normal force results in $\pm Q_E$ or a torque error allowance. This is added alebraically to the Q_H curve, and converts it into a band instead of a line. This allowance is significant for a spade rudder with the rudder stock near the quarter chord point, but is practically negligible for unbalanced rudders.

B) This band is further modified by adding the frictional torque of the rudder bearings. The frictional torque is the result of the rudder bearing reaction, stock bearing radius and bearing friction coefficient. The friction coefficients used are o.01 for anti-friction bearings and o.20 for sleeve type bearings.

C) Minimizing the size of the steering gear requires the balancing of the restoring and upsetting maximum torque of $Q_H \pm Q_E \pm Q_F$. The stock position is adjusted so that maximum restoring torque is 50 percent greater than the maximum upsetting torque. The computer program No. 0305 cannot balance the torque envelope in this way so this step in the procedure must be done by hand.

D) Finally, 25 percent of the maximum torque restoring is added to the torque envelope as a torque allowance Q_A.

E) The calculation for the horn rudder is very similar to the spade rudder except when calculating the frictional force, the normal force F_N is used instead of the resultant force F_R.

3.5.2 Submarine Rudder and Fairwater Plane

The calculation procedure for determining submarine rudder and fair water plane torque requirements is nearly the same as that for surface ship rudders (section 3.5.1) with the differences described below.

Fairwater plane:

1) The torque error allowance Q_E = 1-2% of the mean chord c.
2) Restoring torque = Upsetting torque
3) Design torque = 1.20 x restoring torque.

Rudder:

1) The torque error allowance Q_E = ½ - 1% of the mean chord c.
2) Restoring torque = Upsetting torque
3) No additional allowance Q_A is added to the torque envelope.

3.5.3 Submarine Stern Plane

The calculation procedure for determining the

torque requirements for submarine stern planes is described in section 3.4.3. The torque requirements for stern planes are described below.

Stern Plane: 1) Restoring torque = upsetting torque

2) No additional allowance Q_A is added to the torque envelope.

3.6 References

1. Taplin, A. "Notes on Rudder Design Practice". First Symposium on Ship Maneuverability. DTMB Report 1461. October 1960.
2. Whicker, L. Folger, D. Eng. and Fehlner, Leo F. "Free Stream Characteristics of a Family of Low-Aspect-Ratio, All Moveable Control Surfaces For Application to Ship Design". DTMB Report 933 (Revised Edition). December 1958.
3. Gover, S.C. and Olson, C.R. "A Method for Predicting the Torque of Semibalanced Centerline Rudders on Multiple-Screw Ships". DTMB Report 915. November 1954.
4. Cauldwell, F.S. "Control Surfaces Calculations and Programs". Personal Work - Not published.
5. Naval Ship Engineering Center. "Technical Practices Manual 562 (9220-1) Code 6136". Not published.
6. University of Maryland Wind Tunnel Report No. 320 or AD 436-884 "Free stream characteristics of Four Low-Aspect Ratio, All-moveable Control Surfaces.
7. University of Maryland Wind Tunnel Report No. 485 "Effects of Streamwise Gaps, Hull Flow and Propeller Slipstream Upon the Aerodynamic Characteristics of a Family of Low-Aspect Ratio, All-Moveable Control Surfaces."

4. UPDATED TECHNICAL PRACTICES MANUAL, RUDDERS AND SUBMARINE CONTROL SURFACES 562 (9220-1) (Code 6136)

Note: Only Section 3 of Part A and Sections 3.4, 4.2, 5.1 and 7.1 of Part B are updated here. The material of other sections of the manual are discussed briefly in Section 2 of this report.

A. Rudder Design

Section 3 - Calculation of Rudder Forces, Moments and Balance.

3.1 This section represents recent practice, as revised, to take advantage of AOE 1 and AS 33 lessons from trial data recorded by Puget Sound Naval Shipyard. Analysis of the data indicated the effective attack angle should be taken as 0.75 times rudder angle, rather than 5/7 = 0.71 formerly used. From Puget Sound's AS 33 data some allowance should be made for torque, say 25 percent of maximum at zero rudder for a rudder in a propeller race. DTMB Report 060-H-01 of March 1965 reports model tests of AS 33 forces and torque. Forces correlate well with design theory; torques do not correlate with either design theory or full scale data. The error allowance in estimating chordwise center of pressure should be increased generally (as indicated in paragraph 3.5 which has new values) for so important a system. Regarding specifications, the assumed efficiency from steering gear

hydraulic torque to rudder stock will be stated. In addition to general performance requirements, NAVSEC predicted forces and torques will be specified.

Where weight is of more than usual importance, the design may include more specific requirements than merely performance. This essentially involves taking some risk where weight saving makes that course desirable. The computation is by aerodynamic and hydrodynamic methods with some additional features for ship applications. The publications for this work are references 2, 6 and 7 as listed in 3.6. Forces and centers of pressure are computed as indicated below, and additional allowances are made for converting hydrodynamic torque into steering gear torque.

3.2 The computations for forces and centers of pressures involve finding data for an acceptable range of Reynolds Number and aspect ratio and correcting for:

(a) Effective aspect ratio:

$$\text{A.R. Geometric} = \frac{\text{Span}}{\text{Chord}}$$

$$= \frac{\text{Span}^2}{\text{Area}}$$

A.R. effective varies from 1.0 to 2.0 times geometric, depending on the gap between rudder root and hull.

(b) Taper ratio $\left(\lambda = \frac{\text{tip chord}}{\text{root chord}}\right)$

(c) Sweepback angle (Ω=angle that the quarter chord line makes relative to the stock axis).

(d) Mean chord ($\overline{c}$=(Tip Chord + Root Chord)/2)

3.3 The attack angle (α) for surface ship rudders is usually taken as 0.75 the rudder angle. This is an arbitrary drift angle allowance, based on the time to get the rudder over (about 10 seconds) and the expectation that the ship will have started swinging by then. This arbitrary value transforms a 35 degree rudder angle into a 26.2 degree attack angle, below stall in most wind-tunnel data.

3.4 The speed used is that in way of the rudder during a full-power straight-running period plus one knot. The ship should be assumed to be in a minimum operating condition and clean-bottom condition such as can occur on builders trials. Any reduction of speed in a turn is not considered. For rudders entirely within a propeller race, flow speed is taken from data of a similar ship. If a portion of the rudder is not within the propeller slip stream, a separate calculation is performed for that portion of the rudder using ship speed for the inflow velocity.

3.5 With these simplified methods of estimating flow speed and angle of attack, the ordinary coefficients

(lift, drag, normal force, chordwise and spanwise center of pressure) are obtained by cross-fairing as indicated by Section 3.2. A systematic plot of data by Electric Boat Division (available in Code 6136) is very useful for this. The rudder torque so obtained is called Q_H the hydrodynamic torque. Airplane nomenclature is followed with negative torque indicating a trailing tendency (center pressure aft of stock). An allowance for uncertainty in center of pressure is made generally $\pm$ 3 percent of the mean chord. This allowance, multiplied by the force, results in a $\pm Q_E$, or torque error allowance. This is added algebraically to the Q_H curve, and converts it into a band in lieu of a line (note that no error allowances are made for force or spanwise center of pressure). This band is then further modified to get tiller torque by allowing for the intervening friction torque Q_F. This is done by computing reactions at all bearings, multiplying by a friction coefficient (see section on Bearings) to get the frictional force, and multiplying that by the radius of sleeve or the radius to the center of the rollers to get frictional torque. Finally, 25% of the maximum restoring torque at full rudder angle is added to the torque band

for a torque correlation allowance Q_A. The best example of this systematic procedure and the sources of aerodynamic data are shown in the Code 6136 rudder file for SSB(N) 608 Class.

3.6 Rudder balance may be theoretically selected in this manner: Obtaining the minimum size of steering gear requires balancing the negative or restoring and positive or upsetting torque envelopes of $Q_H \pm Q_E \pm Q_F \pm Q_A$. Allowance can be made for varying mechanical advantage of the steering gear at different rudder angles. For surface ship rudders, it is desirable to have the maximum negative torque 50% greater than the maximum positive torque; this balance is made before the final torque correlation allowance Q_A is added.

3.7 (a) Report 1461 provides the basic procedure for the torque calculation of surface ships with spade rudders. The computer program titled Rudder, Fairwater Plane Design uses the method of report 1461 with the data from DTMB Report No. 933 to perform the torque calculations.

(b) For semi-balanced rudders or horn-type rudders, Joessel's method is used.

3.8 Astern Operation

Astern Operation is usually investigated only for ships having a military requirement for going astern (e.g. LCU types which retract astern). Model tests are then used for determining controllability, since there is no reliable theory.

Astern operation generally does not control scantlings, but does control steering gear capacity. Recent practice has been to design the steering gear for ahead operation and limit sustained astern RPM based on trials so as not to exceed the steering gear capacity. "Sustained" astern RPM is specified so as to still permit the ship to use full astern RPM for crashback. It should be noted that for astern operation the rudders tend to take charge and will move to larger angles, since the center of pressure is well aft of the rudder stock. Accordingly, in going astern with a hydraulic system, when the relief valve opens, the rudder would go to hard over. To avoid this, usual practice is to specify that the safe sustained astern RPM would be determined from sea trials, and that suitable warning plates be installed.

3.9 Sea Slap

See section 7 of Submarine Control Surfaces. The criteria for submarines also applies to surface ships.

3.10 Zig-Zag Maneuvers

Zig-Zag maneuvers should result in greater rudder forces and rudder torques than for simply right or left turning. Although the zig-zag maneuvers are not considered during the design stage, the design procedure is considered conservative enough to cover such maneuvers.

B. Submarine Control Surfaces

Section 3 - Fairwater Planes

3.4 In computing forces and centers of pressure, the angle of attack is taken as the plane angle (unlike Rudder Design Practice, Section 3.3, the diving planes can be operating with no drift angle reduction). The maximum plane angle is 20°. In the balancing of the torque envelope the maximum value of the upsetting curve is equal to the maximum value of the restoring curve. After balancing, a torque correlation allowance (Q_A) equal to 20% of the maximum restoring torque is added.

Section 4 - Stern Planes and Stabilizers

4.2 As with fairwater planes, the angle of attack is taken equal to the plane angle, without any drift corrections. The force and center of pressure determination for the stern plane plus stabilizer combination follows

the same procedure as Section 3.4.1. In the balancing of the torque envelope for stern planes, the maximum value of the positive curve equals the maximum value of the negative curve. No torque allowance Q_A is added. The computer program titled Stern Plane Calculations is used to perform this calculation.

Section 5 - Rudders

5.1 The design calculation of submarine rudder forces is the same as that covered in "Technical Practices A. Rudder Design."

There are a few differences from the procedure used in section A. In the balancing of the negative and positive torque curves for rudders, the maximum value of the positive curve equals the maximum value of the negative curve. No torque correlation allowance Q_A is added.

Section 7 - Sea Slap

7.1 The practice is to assume that sea waves acting on exposed control surfaces are equivalent to a static uniform load of 1000 pounds per square foot.

Under this loading the Ship Specifications usually indicate that

(a) Structure may be stressed up to the yield point (this particularly involves torque keys and keyways).

(b) The control torque may exceed hydraulic gear capacity (because of the long lever arm to sea slap center of pressure).

In that case popping the relief valve is acceptable. On SS(N) 597 the Electric Boat Division made a computer analysis of the response of the hydraulic system to such transient loading. For that purpose NAVSEC arbitrarily indicated that the loading could be taken as $1000 \sin \frac{(2\pi T)}{(0.2)}$ lbs/sq. ft. where T varies from 0 to 0.2 seconds. On newer submarines such as the SSN 688 and TRIDENT, the hydraulic system is built without relief valves. The system is sized such that the anticipated loads (hydraulic or sea slap) will not cause pressures in excess of 1.5 times the system pressure.

5. STATE OF THE ART

5.1 Introduction

The problem of predicting the actuating gear torque of a ship control surface involves the following:

(a) Inflow characteristics of the water about the control surface.

(b) Hydrodynamic characteristics of the control surface.

(c) Mechanical characteristics of the control surface actuating gear mechanism.

The obviously formidable task of exhaustively evaluating the current state of the art of all the areas mentioned is beyond the scope of the subject task. Although each area was touched upon, the only one investigated to a higher degree was that of predicting the hydrodynamic characteristics of the control surface. Particular emphasis was given to this area since it seemed to hold the most promise for an immediate addition to improving control system torque prediction capabilities.

Abstracts of many of the books, papers, and articles reviewed can be found in Appendix E.

5.2 Inflow Characteristics of the Water About A Control Surface

The angle of attack and velocity of a control surface with respect to the fluid around it is a function of many variables. The most important are discussed in the sections below.

5.2.1 Ship Maneuvering

5.2.1.1 Introduction

Whenever a control surface is deflected, the ship will experience an unbalance of forces, which results in rigid body motion of the ship.

As the control surface is deflected, the ship will go into a maneuver which usually has sideslip and decrease in speed of the vessel as a result. Increased turbulence around the hull can also be expected. As a result the water inflow characteristics to the control surface can be considerably altered from the ship straight ahead condition. The rate at which the control surface is deflected bears heavily on the degree to which the above phenomena occur.

Knowledge of the above phenomena would greatly add to the prediction of the control surface inflow direction and speed. Unfortunately, however, this involves very accurate experimental or theoretical methods.

5.2.1.2 Equations of Motion

The maneuvering response of a ship is determined by solving the appropriate equations of motion. Generally speaking, motion stability and tight maneuvering response are of interest.

Motion stability considers the response of the ship after some arbitrary infinitesimal disturbance from the equilibrium condition of straight ahead motion, to see if the ship returns to the original position. When considering this type of motion only the linear terms in the equations of motion need be considered.

For dynamically stable ships (stability in straight line motion) the linear theory holds for moderate maneuvers and non-linear terms become necessary only for tight maneuvering. For unstable ships, higher order terms are necessary to determine maneuvering properties.

Although the linear equations of motion can be solved in a closed form once the coefficients have been determined by experimental or theoretical techniques, the non-linear equations of motion cannot be solved directly, but must be evaluated in a step by step computer integration procedure.

5.2.1.3 The Hydrodynamic Coefficients of the Equations of Motion

The equations of motion include many hydrodynamic coefficients which depend on ship shape, size, inertia distribution and the equilibrium condition involved in the analysis. Numerical quantities for these must be determined for the ship under consideration in order to determine the response.

Generally, theoretical means are not available for calculating these coefficients accurately. It then becomes necessary to obtain these from the results of special model tests in a towing tank, water tunnel, wind tunnel, etc., or use the results of a series of model tests which have a systematic shape variation about a parent form.

Special equipment and techniques have been developed for obtaining the required information from model tests. Such equipment consists of oscillators, planar motion mechanisms, rotating arm facilities, etc.

5.2.1.4 Conclusions Regarding Ship Maneuvering

Although calculations have shown that ship maneuvering can be predicted in some instances, this cannot be generally assumed for all maneuvers and ships. In addition, the predicted maneuvers involve determining the hydrodynamic coefficients of the subject ship by conducting expensive model tests. Published data giving hydrodynamic coefficients for the equations of motion for systematically varied series are not known to exist.

Therefore, at this time it is difficult and expensive to predict the maneuvering characteristics of a ship. In addition it is not known if all maneuvers will give realistic results.

5.2.2 Boundary Layer of the Ship Hull

It is well known that the viscosity of water will cause a boundary layer to form over the ship length with the effect that the water velocity in way of the control surface will be nonuniform. The degree of nonuniformity will directly depend on the location of the control surface on the ship.

The prediction of the velocity distribution in this boundary layer is necessary in order to compute the inflow velocity of water into the control surface.

This subject has been the main topic of investigation for many research works in the field of naval architecture. As of the present time these investigators know of no way to accurately predict the boundary layer characteristics of the flow about a ship by theoretical means.

Many experimental model surveys of the wake area behind the ship exist for a varied amount of ship types. It is still normal procedure to estimate the wake for a new design from the experimental data of other ships. This estimated wake may be revised if model tests of the subject ship are done at a later date.

5.2.3 Propeller Race and Appendage Wake

Many times, particularly in the case of the rudder, the control surface is located behind a propeller and appendages, such as propeller shafts, struts and bossings. These alter the direction and speed of the flow into the control surface.

The appendages affect the boundary layer of the ship in their vicinity. Since ship wake surveys are performed

with appendages attached, this aspect need not be considered independently.

Besides increasing the speed of flow into the control surface within it, the propeller race contracts and expands as the loading on the propeller changes. This may cause the rudder to be completely enveloped by the race in some cases and not in others. Unfortunately, this phenomena has not been the subject of many investigations and no general conclusions can be drawn.

5.3 Hydrodynamic Characteristics of the Control Surface

5.3.1 Introduction

In the current porocedure assumptions are made with regard to the caracteristics of the flow to the control surface and an effective angle of attack and flow velocity are determined. Free stream hydrodynamic characteristics (lift, drag, center of pressure) from experimental data are then used to determine the forces and moments on the control surface shaft. Planforms and section shapes for which test data do not exist are approximated by interpolation and extrapolation of planforms and section shapes for which data does exist.

A survey of the state of the art has shown that two distinct areas of effort in developing control or lift surface characteristics have been followed, mainly experimental and theoretical. The most extensive work has been in the aero-

nautical field and in recent times has dealt almost exclusively with theoretical approaches. Elegant methods for predicting wing and control surface characteristics now exist.

Some of the theoretical procedures investigated allow the calculations to be performed for arbitrary surfaces with or without thickness and also allow for the effects of a nearby body.

5.3.2 Experimental Methods

5.3.2.1 Introduction

The most extensive experimental data available outside of the DTMB 933 report are found in the aeronautical literature. Unfortunately many of the section shapes used for aeronautics are different from those used for ship control surfaces. In addition, since aeronautical planforms usually have significantly higher aspect ratios, two-dimensional model testing techniques are used instead of using the complete planform. Thus the crossflow and tip effects are neglected.

5.3.2.2 Testing Techniques

A. Tests with finite-aspect-ratio wings.

This method of testing is hampered by the difficulties of obtaining full-scale values of the Reynolds

number and sufficiently low air stream turbulence to duplicate flight conditions properly without excessive cost for equipment and models (Like DTMB 933).

B. Two-dimensional testing.

With this method sections are tested in a two-dimensional flow at large Reynolds numbers in an air-stream of very low turbulence, approaching that of the atmosphere. This is made use of particularly for aeronautical purposes.

5.3.2.3 Results of Experiments

The varied model experiments indicate that Reynolds number effects are limited to increasing the stall angle (without changing lift curve slope) and decreasing the drag (up to a certain limit) with increasing Reynold number. Since ship control surface angles of attack do not usually reach stall, the first fact is not of particular interest. It appears from the literature that at the high Reynolds number experienced on ship control surfaces, the drag remains constant for a given lift, over a large range of the Reynolds numbers. For the range of Reynolds numbers in DTMB 933, the drag increases with decreasing Reynolds number. Since the drag is important for estimating the location of the resultant force on the control surface, error may result from using DTMB 933 data for cases with considerably higher Reynolds numbers (as with full scale ships).

It should be noted that the above facts and conclusions were from two-dimensional model tests instead o6 the thhee-dimensional type of DTMB 933. Therefore the effects of the control surface tip and crossflow are not considered. The inclusion of these could alter the results.

Surface roughness, especially near the leading edge, has large effects on control surfaces, decreasing the lift and increasing the drag.

5.3.3 Theoretical Techniques

5.3.3.1 Introduction

The development of the theory of flow past a finite wing has advanced considerably over the years.

The first mathematical formulation of the theory was made by Prandtl (in 1918) for straight wings of large aspect ratios. The ideas underlying Pradtl's theory are important and have served as the basis for further developments of the finite wing theory.

The models currently in use for calculating the flow past a finite wing are the lifting line theory and lifting surface theory.

All available theoretical computer programs neglect the effect of viscosity and only determine the potential flow. The only drag derived is the induced drag. Since experimental results indicate that the viscous effects (Reynolds number effects) are not of any appreciable

magnitude for ship control surfaces, the theoretical assumptions regarding the neglection of viscosity may be acceptable for the purpose of calculating control surface torque requirements.

5.3.3.2 Lifting Line Theory

For a control surface with the characteristics listed below, the lifting line theory can be applied:

A. The control surface has a median plane of symmetry.

B. The aspect ratio is equal to or greater than about 4.

C. The trailing edge is approximately a straight line.

The wing is then replaced by a system of bound vortices distributed along a straight line coinciding with the span of the control surface.

The lifting line theory has been applied to many types of wings and control surfaces usually utilizing empirical correction factors.

Calculations including propellers with nonuniform streams forward of a nearby wing of high aspect ratio modeled by the lifting line theory have given realistic results of aerodynamic properties of the wing.

The lifting line theory cannot yield realistic results for small aspect ratios without the use of empirical corrections. The theory also cannot rigorously

account for flaps and sweepback.[1]

5.3.3.3 Lifting Surface Theory

If the wing or control surface is replaced by a system of bound vortices distributed over its surface (rather than along a straight line as in the lifting line theory) or as an assemblage of finite elements, the wing or control surface can be modelled much more accurately. Thickness effects, sweepback, and flaps can be included. Note the existence of two methods, namely the collocation (distributed vortices) and the finite element.[2]

The state of the art of the lifting surface theory is continually advancing because of its use to the aeronautical industry. Computer programs are now in existence which can predict the aerodynamics of wings of arbitrary shape with Mach number, thickness, flaps, small aspect ratio, and the presence of a fuselage included.

The present state of available computer programs with respect to their capabilities is not known since this is continually changing. In particular it is not known if nonuniform flows (this should not be a severe addition, if not already included) can be considered.[3] Therefore it is impossible to say without further research whether or not existing computer programs are applicable to the ship problem.

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1 See Reference #17.
2 See References #2 and #3.
3 See Reference #18.

The literature also indicates the computer time and expense of utilizing lifting surface programs is not excessive.

5.4 Mechanical Characteristics of the Control Surface Actuating Mechanism

The extent to which the actuating mechanism has been considered is to the tiller. Therefore, the only item that can affect the steering gear torque is the bearing friction.

No work additional to that used in developing the current procedure has been found in the literature.

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6. RECOMMENDATIONS

6.1 Introduction

The recommendations are divided into three parts. This was done in order to put into proper perspective the level of effort involved in performing them as well as the sequence in which they should be completed.

The trend has been to avoid experimental investigations whenever possible and rely on theoretical techniques since these involve considerably less cost in development.

The three different groups of recommendations are as follows:

1. Possible moderate revisions to the present procedure should be considered for implementation. Also, the present computer programs used by NAVSEC for estimating rudder torque should be revised as soon as possible to include the current procedure as presented in its final form in this report.

2. Given the inflow characteristics, it appears that current theoretical lifting surface theory may be able to predict accurately the hydrodynamic characteristics of ship control surfaces. The determination of whether this can be done or not should be undertaken as soon as possible.

3. Since the prediction of control surface inflow characteristics involves so many considerations for which

theoretical and experimental tools and information are not available, it is felt that this area should be considered as one in which large gaps in the technology exist. This is considered the area where a high level of effort is needed.

6.2 Revisions Associated with Current Procedure

The horn rudder should be considered as the combination of a flapped rudder (portion with horn) and spade rudder (portion below horn). This modification is considered possibly more appealing than the current method. Comparison with experimental data will indicate the value of this proposed modification.

Also, the current NAVSEC computer programs should be revised so that any desired balance of maximum steering gear torque can be obtained.

6.3 Use of Lifting Surface Theory for the Prediction of Control Surface Hydrodynamic Characteristics

Existing lifting surface theory and corresponding computer programs are available which may be able to determine the hydrodynamic characteristics of arbitrary control surfaces with the consideration of the nearby hull as described in Section 5. Also, the computation time and expense involved in carrying out the calculations appear reasonable. Therefore, the application of these programs to ship control surfaces

should be investigated as soon as possible. It should be noted that the inflow characteristics (speed and direction) must be known for input to these programs.

Karl E. Schoenherr in his paper "A Program for an Investigation of the Rudder-Torque Problem" (Marine Technology, July 1965 - See Appendix E for abstract), outlined a proposed program for future work in the area of predicting rudder torque. His first suggestion was to improve the theory of low-aspect-ratio airfoils with special reference to rudders. This has been done with the lifting surface theory although not with special reference to rudders. He then suggested that all known information on rudders be gathered, formulas developed for C_D, C_L and C_M, and free stream tests be done for flapped and horn rudders and for hull proximity effects.

The present investigators feel the Schoenherr approach is excellent but should be modified in light of the theoretical methods now available. The following is the proposed program:

1. Collect all experimental data applicable to ship control surfaces, including hydrodynamic characteristics, gap effects, and effects of the nearby hull.

2. Conduct a study of current lifting surface theory programs to determine full capabilities with respect

to ship control surfaces. In addition the level of effort for making any modifications should be evaluated.

3. Choose the most suitable program, make any revisions, then run example calculations for all types of control surfaces with nearby hulls to compare with the experimental information of 1. The control surfaces should include spade, flapped, and horn types. It should be noted that without hull and nonuniform stream effects, the program could be used to generate free stream data at considerably reduced costs than model tests.

4. If correlation with experiment is good, this program should be used for computing hydrodynamic characteristics of ship control surfaces. Otherwise, further testing as outlined by Schoenherr will have to be considered.

6.4 <u>Prediction of Inflow Characteristics</u>

Schoenherr goes on to suggest extensive manned model testing to determine all aspects of the rudder torque problem including propeller, rudder and hull interactions; rudder hydrodynamic characteristics; ship maneuvering characteristics. He also suggests design of a torsion meter for measuring rudder torque on full scale ships and conducting full-scale tests on a few selected

ships to check the results obtained in the special test models.

As pointed out in Section 5 the determination of control surface inflow characteristics involves the areas of maneuvering and wake, where knowledge does not exist to very accurately predict results on any ship. Further developments in these areas would require extensive experimental work.

The present investigators feel that once the capability exists for predicting accurately the hydrodynamic characteristics of arbitrary control surfaces as outlined in Section 6.3 given the inflow character, the accuracy of the inflow assumptions can be checked and revised by conducting full-scale trial tests. This can be done by measuring rudder torques on ships during planned maneuvers. The hydrodynamics characteristics for the control surface-ship combination can be determined by the method from 6., by making appropriate inflow assumptions (as in the current procedure). The predicted torques should correspond to the measured torques. If not it is hoped trends will be noticed that will allow general conclusions to be drawn about inflow direction and speed to correct the original inflow assumptions.

The following is the proposed sequence of events:

1. Design a torsion meter for measuring control surface torque on full-scale ships.

2. Using the method chosen from Section 6.3, calculate the hydrodynamic characteristics of control surfaces of several existing ships by assuming the inflow characteristics based on the current procedure.

3. Run planned full-scale maneuvering experiments with the ships used in 2. and measure torques on either side of the bearings and simultaneously measure ram pressures.

4. Compare the results from 2. with those measured in 3. If close correlation exists, an accurate engineering procedure exists. If correlation does not exist, look for trends and correct the assumptions of inflow if possible.

APPENDIX A

Computation of Rudder Forces and Torques for a Spade Rudder

APPENDIX A

COMPUTATION OF RUDDER FORCES AND TORQUES FOR A SPADE RUDDER

GIVEN: A spade rudder as shown in Figure 1 is in the race of a propeller. At maximum ship speed of 30 knots, the propeller slip is 17.2 percent. The rudder is close enough to the hull so that full reflection (double the geometric aspect ratio) can be assumed at 0-deg rudder angle; also assume linear decrease to 1.0 times geometric aspect ratio at full rudder angle of 35 deg. The rudder has NACA OOXX sections and square tips. Roller bearings are used on the rudderstock.

TO FIND: Forces and torques throughout the range of rudder angles.

PROCEDURE:

Rudder area = 11.35 ft x 9.01 ft = 102.3 sq ft

$$\text{Taper ratio} = \frac{\text{tip chord}}{\text{root chord}} = \frac{5.59 \text{ ft}}{12.43 \text{ ft}} = 0.45, \text{ so}$$

that NACA 0015 curves of TMB 933 apply without taper ratio correction.

The step-by-step procedure is tabulated below. In this example, subscript 1 refers to data taken directly from TMB 933, and subscript 2 refers to desired data. Additional information, where the tabulation is not self-explanatory, is:

Line 2. Take effective angle of attack = 0.75 rudder angle.

Line 3. The geometric aspect ratio is $\frac{(\text{span})^2}{\text{area}} = \frac{(11.35)^2}{102.3} = 1.26$

Use 1.26 at 26.3-deg attack angle, and prorate other angles for 2 x 1.26 at 0-deg attack angle.

Line 4. Reynolds number for ship, based on rudder mean chord

$$\frac{(56.4 \text{ ft/sec}) (9.01 \text{ ft})}{0.000015 \text{ sq ft/sec}} = 34 \times 10^6$$

This is about ten times greater than the highest Reynolds number in TMB 933. Use the highest Reynolds test values in TMB 933 as being the closest. Obtain lift coefficient C_L by interpolating and fairing from Figures 45, 60 and 67 of TMB 933 for sweep angle $\Omega = 11$ deg. See line 19 for the calculation of ship speed.

Line 5. Similar to Line 4, except for $\Omega = 0$ deg use Figures 44, 55 and 66.

Line 6. Straight line interpolation for the desired sweep angle $\Omega = 9\text{-}1/2$ deg.

Line 7. Similar to lines 4 and 5 except read drag coefficient C_D, and no interpolation is needed.

Line 8-11. Lift and drag are used in the conventional aeronautical sense of forces normal to and in line with the flow. Lines 10 and 11 are the normal components of lift and drag coefficients.

Line 12. The normal force coefficient, for use in computing hydrodynamic torque, is Line 10 plus Line 11.

Line 13. Interpolate from Figures 45, 60, and 67 of TMB 933 to get the chordwise center of pressure, aft of mean chord leading edge.

Line 14. Interpolate from Figures 44, 55, and 66.

Line 15. Straight line interpolation between Lines 13 and 14 for the desired sweep angle of 9-1/2 deg.

Line 18. The sign convention is that used for aeronautical control surfaces. Plus values indicate moments tending to drive the rudder to larger angles. Minus values indicate moments tending to restore the rudder to 0 deg.

Line 19. Propeller race speed = (1 + slip) (ship speed) = (1 + 0.172) (30 x 1.69 ft/sec) = 59.4 ft/sec

Estimated effective speed of flow over rudder = 95 percent x 59.4 = 56.4 ft/sec

$$q = \text{Unit dynamic pressure} = \frac{\rho}{2} v^2 = \frac{1.99}{2} \frac{\text{lb sec}^2}{\text{ft}^4} (56.4 \text{ ft/sec})^2$$

$$= 3170 \text{ lb/ft}^2$$

$$Sq = \text{Dynamic pressure on rudder} = (3170 \text{ lb/ft}^2)(102.3 \text{ ft}^2)$$

$$= 325{,}000 \text{ lb}$$

To get Line 19, multiply 325 kips by the normal force coefficient from Line 12.

Line 20 Line 19 times Line 18.

Line 21. This is the arbitrary error allowance of 3 percent of mean chord. The mean chord is 108.12 in., from Figure 1.

Line 22. This is the torque error allowance, Line 21 times Line 19.

Line 23. The resultant force coefficient $C_R = \sqrt{(C_L)_2^2 + (C_D)_2^2}$

Line 24. The resultant force is Line 23 times 325 kips.

(see also explanation for Line 19.)

Line 25. The spanwise center of pressure at 26.3 degrees attack angle is, from TMB 933, about 49 percent span, or (0.49) (11.35 ft) = 5.562 ft from root chord. From the given bearings locations, the spanwise CP is then 5.562 ft + 1.021 ft = 6.583 ft below the centerline of lower bearing.

Assume a double ram steering gear, which applies torque without side force. Using the resultant force F_R from Line 24 the upper bearing radial load $F_U = F_R \dfrac{6.583 \text{ ft}}{6.333 \text{ ft}} = 1.039\ F_R$

The lower bearing radial load $F_L = F_R + 1.039\ F_R = 2.039\ F_R$

By separate calculation, the radii to center of rollers are: $R_U = 8.65$ in. and $R_L = 14.5$ in. Use coefficient of friction 0.01. The total frictional torque is then $0.01 \left[F_U R_U + F_L R_L \right] = 0.01 \left[(1.039\ F_R)(8.65 \text{ in.}) + (2.039\ F_R)(14.5 \text{ in.}) \right] = 0.386\ F_R$

Line 25 is then Line 24 times 0.386.

Lines 26-29. These involve addition of the error and friction allowances to get an envelope of torque as shown in the plot of "Final Torque Curves," Figure 2

Lines 30-32 These involve addition of 25 percent of the maximum torque in lines 28 and 29 obtain steering gear torque.

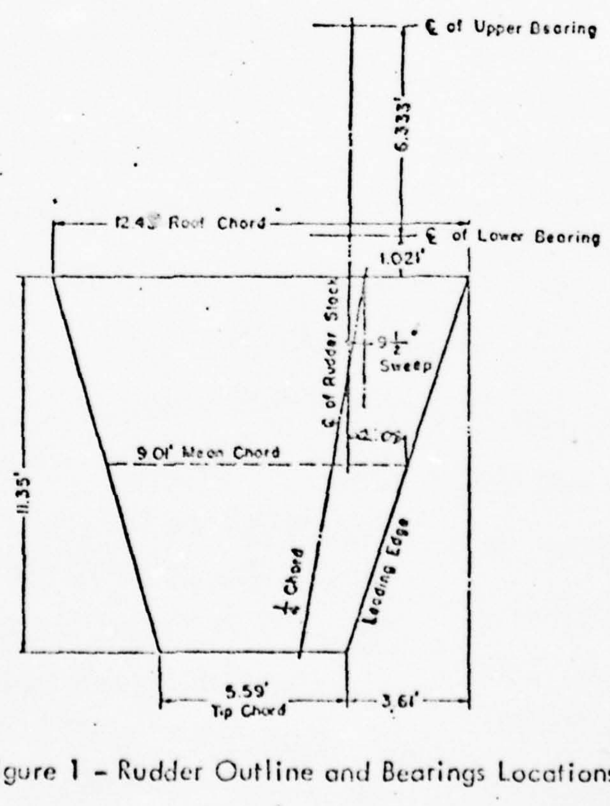


Figure 1 - Rudder Outline and Bearings Locations

TABULATION OF CALCULATIONS FOR APPENDIX A

Line							
1	Rudder Angle, deg.	6.7	13.3	20.0	26.7	33.3	35
2	Angle of Attack α, deg	5.	10	15	20	25	26.3
3	Effective Aspect Ratio	2.28	2.04	1.80	1.56	1.32	1.26
4	C_{L_1} at $\Omega = 11^\circ$	0.237	0.451	0.637	0.807	0.946	0.984
5	C_{L_1} at $\Omega = 0^\circ$	0.229	0.435	0.625	0.792	0.931	0.966
6	C_{L_2} at $\Omega = 9\ 1/2^\circ$	0.236	0.449	0.635	0.805	0.944	0.982
7	$C_{D_1} \cong C_{D_2}$	0.015	0.043	0.088	0.155	0.244	0.270
8	$\cos \alpha$	0.99619	0.98481	0.96593	0.93969	0.90631	0.89650
9	$\sin \alpha$	0.08716	0.17365	0.25882	0.34202	0.42262	0.44310
10	$C_{L_2} \cos \alpha$	0.2351	0.4422	0.6134	0.7565	0.8556	0.8804
11	$C_{D_2} \sin \alpha$	0.0013	0.0075	0.0728	0.0530	0.1031	0.1196
12	C_{N_2}	0.2364	0.4497	0.6362	0.8095	0.9587	1.0000
13	$\frac{(CP)}{c}$ from LE at $\Omega = 11^\circ$	0.1836	0.1945	0.2086	0.2286	0.2636	0.2617
14	$\frac{(CP)}{c}$ from LE at $\Omega = 0^\circ$	0.1866	0.1948	0.2080	0.2244	0.2476	0.2550
15	$\frac{(CP)}{c}$ from LE at $\Omega = 9\ 1/2^\circ$	0.1840	0.1945	0.2085	0.2280	0.2528	0.2603
16	$\frac{(CP)}{c}$ from LE at $\Omega = 9\ 1/2^\circ$, in.	19.89	21.03	22.54	24.65	27.33	28.20
17	CL Stock from LE, in.	25.00	25.00	25.00	25.00	25.00	25.00
18	Torque Arm, in.	+5.11	+3.97	+2.46	+0.35	-2.33	-3.20
19	Normal Force F_N, kips	76.8	146.2	206.8	263.1	311.6	325.0

Lines 20 - 31 continued on following page

TABULATION OF CALCULATIONS FOR APPENDIX A

Line							
1	Rudder Angle, deg	6.7	13.3	20.0	26.7	33.3	35
20	$Q_{H'}$ kip-in.	+392	+580	+509	+92	-726	-1040
21	Allowance Torque Arm, in.	3.24	3.24	3.24	3.24	3.24	3.24
22	Q_E kip-in.	249	474	670	852	1010	1053
23	Resultant Force Coefficient	0.236	0.451	0.641	0.820	0.975	1.018
24	Resultant Force, kips	77	147	208	267	317	331
25	$Q_{F'}$ kip-in.	30	57	80	103	122	128
26	$Q_H + Q_E$ kip-in.	+641	+1054	+1179	+944	+284	+13
27	$Q_H - Q_E$ kip-in.	+143	+106	-161	-760	-1736	-2093
28	$Q_H + Q_E + Q_{F'}$ kip in	+671	+1111	+1259	+1047	+406	+141
29	$Q_H - Q_E - Q_{F'}$ kip-in	+113	+49	-241	-863	-1858	-2221
30	Q_A kip-in	+555	+555	+555	+555	+555	+555
31	$Q_H-Q_E-Q_F-Q_A$	-442	-506	-796	-1418	-2413	-2776
		1234	1666	1814	1602	961	696

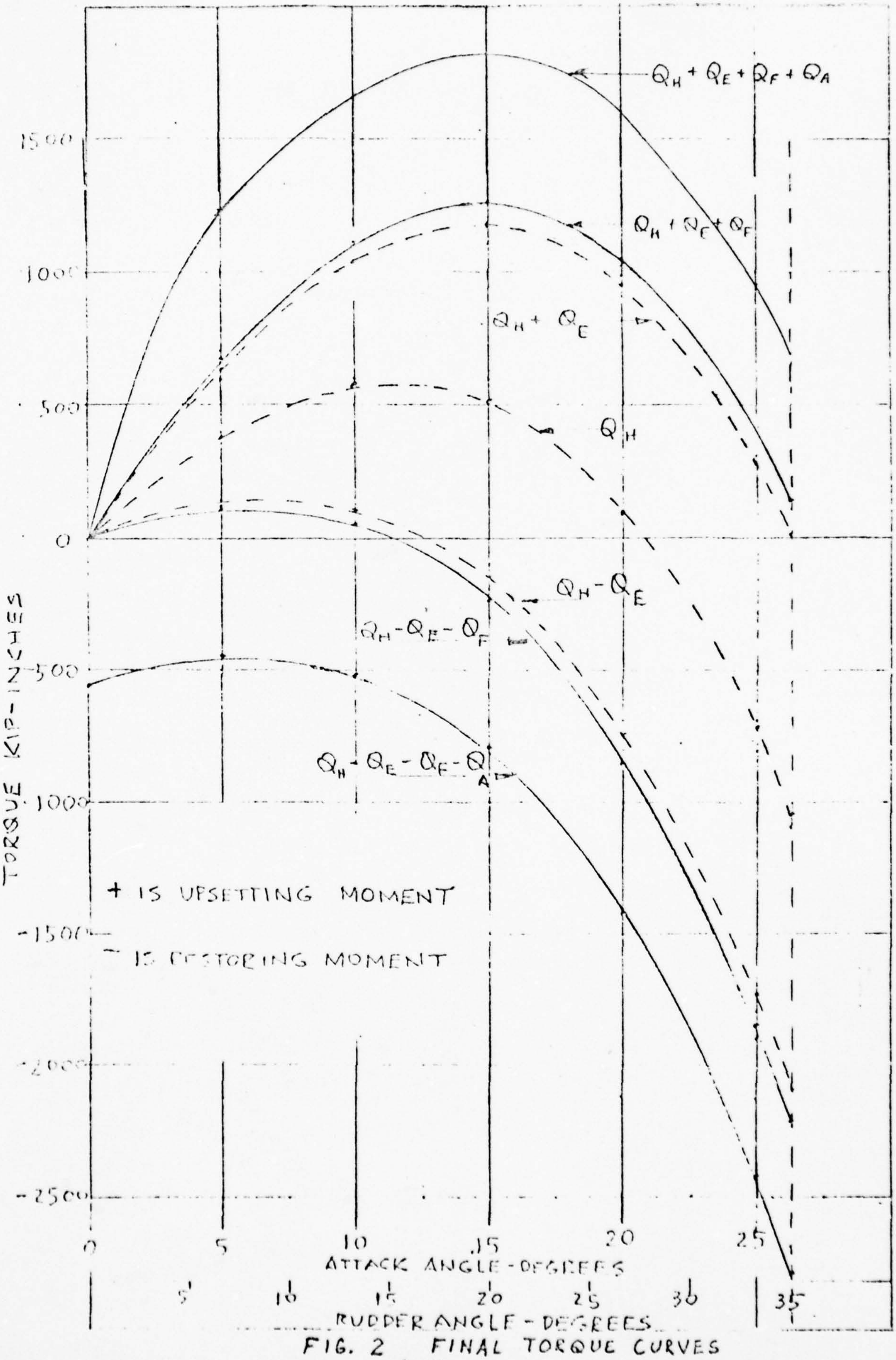


FIG. 2 FINAL TORQUE CURVES

APPENDIX B

Correction for Taper Ratio

APPENDIX B

CORRECTION FOR TAPER RATIO

GIVEN: A control surface has square tips and a taper ratio $\lambda = 0.78$. The following characteristics for $\lambda = 0.45$ have been obtained from TMB Report 933:

Rudder angle, deg	6.7	13.3	20.0	26.7	33.3	35
Attack angle α, deg	5	10	15	20	25	26.3
Effective aspect ratio a_e	1.72	1.54	1.36	1.18	1.00	0.95
Lift coefficient C_L	0.193	0.373	0.534	0.673	0.787	0.817
Drag coefficient C_D	0.011	0.041	0.083	0.146	0.230	0.252
Normal force coefficient C_N	0.193	0.373	0.538	0.683	0.810	0.840
Resultant force coefficient C_R	0.193	0.373	0.539	0.686	0.815	0.849
Chordwise center of pressure (aft of leading edge of mean chord) CP_{LE}	0.175	0.189	0.209	0.235	0.266	0.274

TO FIND: Equivalent values for $\lambda = 0.78$.

PROCEDURE: For convenience, use subscript 1 for the given values ($\lambda_1 = 0.45$) and subscript 2 for the desired values ($\lambda_2 = 0.78$). Referring to Figure 28 of TMB 933, the crossflow drag-coefficients are: $(C_{D_c})_2 = 1.335$

$(C_{D_c})_1 = 0.800$

$$(C_{D_c}') = (C_{D_c})_2 - (C_{D_c})_1 = 0.535$$

From Equation [1] of TMB 933 we obtain:

$$\Delta C_L = (C_L)_2 - (C_L)_1 = \frac{(\Delta C_{D_c})(\alpha r)^2}{a_e}$$

Where αr is the attack angle in radians. This is used in Line 6 of the detailed calculation sheet.

From Equation 2 of TMB 933 we obtain:

$$\Delta C_D = \frac{(C_L)_2^{\ 2} - (C_L)_1^{\ 2}}{2.83\, a_e}$$

This is used in Line 12 of the detailed calculation sheet.

From Equation 4 of TMB 933 we obtain:

$$\Delta (Cm_{\frac{c}{4}}) = -\frac{1}{2}\Delta C_L$$

This is used in Line 24 of the detailed calculation sheet.

The tabulation that follows is intended to be in aform that permits checking step-by-step. Certain operations are indicated by line number, for further clarification.

TABULATION OF CALCULATIONS FOR

APPENDIX B

Line								
	1	Rudder angle, deg	6.7	13.3	20.0	26.7	33.3	35
	2	Attack angle α, deg	5	10	15	20	25	26.3
	3	Attack angle α_r	0.0873	0.1745	0.2618	0.3491	0.4363	0.4590
	4	$(\alpha_r)^2$	0.00762	0.0305	0.0685	0.1219	0.1904	0.2169
	5	α_e	1.72	1.54	1.36	1.18	1.00	0.95
	6	$\Delta C_L = \frac{(0.535)(\alpha_r)^2}{\alpha_e}$	0.002	0.011	0.27	0.055	0.102	0.122
	7	$(C_L)_1$	0.193	0.373	0.534	0.673	0.787	0.817
	8	$(C_L)_2 = (C_L)_1 + \Delta C_L$	0.195	0.384	0.561	0.728	0.889	0.939
	9	$(C_L)_2^2$	0.03802	0.14746	0.31472	0.52998	0.79032	0.88172
	10	$(C_L)_1^2$	0.03725	0.13913	0.28516	0.45293	0.61937	0.66749
	11	$(C_L)_2^2 - (C_L)_1^2$	0.00077	0.00833	0.02956	0.07705	0.17095	0.21423

TABULATION OF CALCULATIONS (CONT.)

Line								
	1	Rudder angle, deg	6.7	13.3	20.0	26.7	33.3	35
	12	$\Delta C_D = \frac{(C_L)_2^2 - (C_L)_i^2}{2.83\, a_e}$	0.0002	0.0019	0.0077	0.0231	0.0604	0.0726
	13	$(C_D)_1$	0.011	0.041	0.083	0.146	0.230	0.252
	14	$(C_D)_2 = (C_D)_1 + \Delta C_D$	0.0112	0.0429	0.0907	0.1691	0.2904	0.3246
	15	$(C_N)_1$	0.193	0.373	0.538	0.683	0.810	0.840
	16	$\cos \alpha$	0.9962	0.9848	0.9659	0.9397	0.9063	0.8965
	17	$\sin \alpha$	0.0872	0.1736	0.2588	0.3420	0.4226	0.4431
	18	$(CL)_2 \cos \alpha$	0.1943	0.3782	0.5419	0.6841	0.8057	0.8418
	19	$(C_D)_2 \sin \alpha$	0.0010	0.0074	0.0235	0.0578	0.1227	0.1438
	20	$(C_N)_2$	0.195	0.386	0.565	0.742	0.928	0.986
	21	$(CP_{LE})_1$	0.175	0.189	0.209	0.235	0.266	0.274
	22	$(CP_{c/4})_1 = 0.25 - (CP_{LE})_1$	+0.075	+0.061	+0.041	+0.015	-0.016	-0.024
	23	$(C_{m\ c/4})_1 = (CP_{c/4})_1\ (CN)_1$	+0.0145	+0.0227	+0.0220	+0.0102	-0.0129	-0.0202

TABULATION OF CALCULATIONS (CONT.)

Line								
	1	Rudder angle, deg	6.7	13.3	20.0	26.7	33.3	35
	24	$\Delta(C_{m_{c/4}}) = -\frac{1}{2}\Delta C_L$	-0.0010	-0.0055	-0.0135	-0.0275	-0.0510	-0.0610
	25	$(C_{m_{c/4}})_2 = (C_{m_{c/4}})_1 + \Delta(C_{m_{c/4}})$	+0.0135	+0.0172	+0.0085	-0.0173	-0.0639	-0.0812
	26	$(CP_{c/4})_2 = (C_{m_{c/4}})_2 \div (C_N)_2$	+0.0692	+0.0446	+0.0150	-0.0233	-0.0688	-0.0824
	27	$(CP_{LE})_2 = 0.25 - (CP_{c/4})_2$	+0.1808	+0.2054	+0.2350	+0.2733	+0.3188	+0.3324
	28	$(C_D)_2^2$	0.00013	0.00184	0.00823	0.02859	0.08433	0.10537
	29	$(C_R)_2^2 = (C_L)_2^2 + (C_D)_2^2$	0.3815	0.14930	0.32295	0.55857	0.87465	0.98709
	30	$(C_R)_2$	0.618	0.386	0.569	0.747	0.935	0.994

APPENDIX C

Computation of Rudder Forces and Torques for a Horn Rudder

Appendix C

Computation of Rudder Forces and Torques for a Horn Rudder

GIVEN: The horn rudder of the USS Alaska (CB1) which is outside of the race of the propellers. Since the rudder is not directly behind the propeller, slip is taken into account. The ship speed is 31.4 knots. The shape parameters of the rudder are given in table 1.

To Find: Forces and torques throughout the range of rudder angles.

Procedure: The step by step procedure is tabulated below.

Torque of Lower Portion

Line 1 Enter figure 3 with h_1/c_1 ratio and for each rudder angle find C_N.

Line 2 Determine the normal force F_1 with the equation $F_1 = C_N (\rho/2) AU^2$

Line 3 Enter figure 4 with the h1/c1 for each rudder angle.

Line 4 Subtract the ratio of the distance of the rudder stock to the leading edge from the distance of the center of pressure to the leading edge to obtain the moment arm.

Line 5. Multiply the value in line 4 by the chord length C_1 to obtain the moment arm.

Line 6. Multiply the force (Line 2) by the moment arm (Line 5) to obtain the torque of the lower portion Q_1.

Torque of Upper Portion

Line 7. Enter figure 3 with the $^{h}2/c_2$ ratio and for each rudder angle find C_N.

Line 8. Determine the normal force F_2 with the equation $F_2 = C_N \, (\rho/2) \, AU^2$.

Line 9. Enter figure 4 with the $^{h}2/c_2$ ratio and find the distance of the center of pressure to chord length ratio $^{x}2/c_2$.

Line 10 Multiply the value of line 9 by the chord length C_2 to obtain the moment arm x_2.

Line 11 Multiply the force (line 8) by the moment arm (line 10)to obtain the torque for the upper portion Q_2.

Line 12 Add the values of line 6 and 7 Q_1+Q_2 to obtain the total hydrodynamic torque Q_H.

Total Torque

Line 13. Add the forces of the lower and upper portions $F_N = F_1 + F_2$ and assume that the normal force F_N is equivalent to the resultant force F_R.

Line 14 Find the frictional torque Q_F using the resultant force (line 13). By separate calculation, the total frictional torque equals 2.75 (F_R) for sleeve bearings and 0.14 (F_R) for roller bearings.

For the purposes of this calculation, we shall assume the bearings are roller bearings. Therefore, to find the frictional torque, use $Q_F = 0.14\ (F_R)$.

Line 15 Q_A is an additional allowance. For roller bearings and sleeve bearings, the torque allowances are 25 and zero percent of the maximum rudder torque, respectively.

Line 16 - 17 Summation for the torque curves of the envelope.

TABLE 1

Definition of Parameters

A_1	Projected area of lower portion of semibalanced rudder
A_2	Projected area of upper portion of semibalanced rudder
c_1	Mean chord of lower portion of rudder
c_2	Mean chord of upper portion of rudder (taken to centerline of rudder stock)
C_N	Normal force coefficient, where $C_N = C_L \cos\delta + C_D \sin\delta$
d	Length from leading edge of lower portion to centerline of rudder stock, measured along mean chord
F_1	Normal force on lower portion of rudder
F_2	Normal force on upper portion of rudder
h_1	Span of lower portion of rudder
h_2	Span of upper portion of rudder (measured at rudder stock)
Q	Torque of rudder about rudder stock
U	Velocity of ship in feet per second
v	Velocity of ship in knots
x_1	Distance measured along c_1 for location of center of pressure of lower portion from leading edge
x_2	Distance measured along c_2 for location of center of pressure from centerline of rudder stock
δ	Rudder angle
ρ	Mass density of water

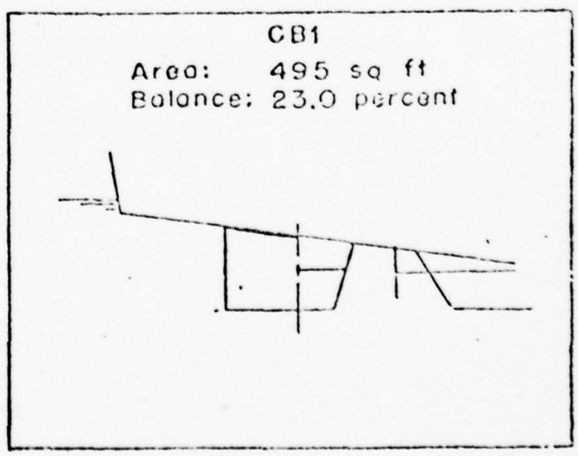
Table 2

Shape Parameters for the CB1 Rudder

All dimensions are in feet and square feet

Parameters	CB 1
A_1	309.6
h_1	10.67
c_1	29.02
d	10.69
h_1/c_1	0.368
d/c_1	0.368
A_2	185.9
h_2	8.83
c_2	18.33
h_2/c_2	0.482
$h_1 + h_2$	19.50
$(h_1 + h_2)^2$	380.3
$A_1 + A_2$	495.5
$\frac{(h_1 + h_2)^2}{A_1 + A_2}$	0.768

Parameters	CB1
$\frac{A_2}{A_1 + A_2}$	0.375
$\frac{dh_1}{A_1 + A_2}$	0.230



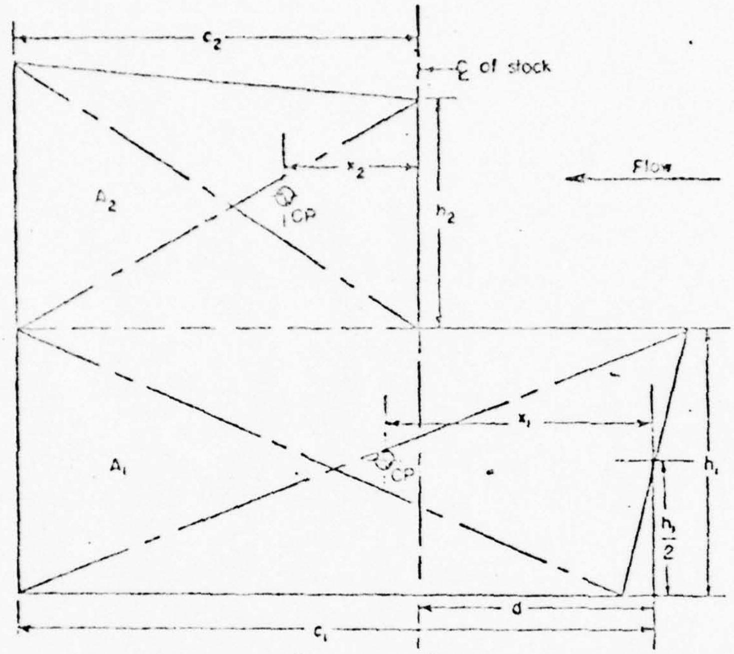


Figure 2 - Typical Rudder with Notations

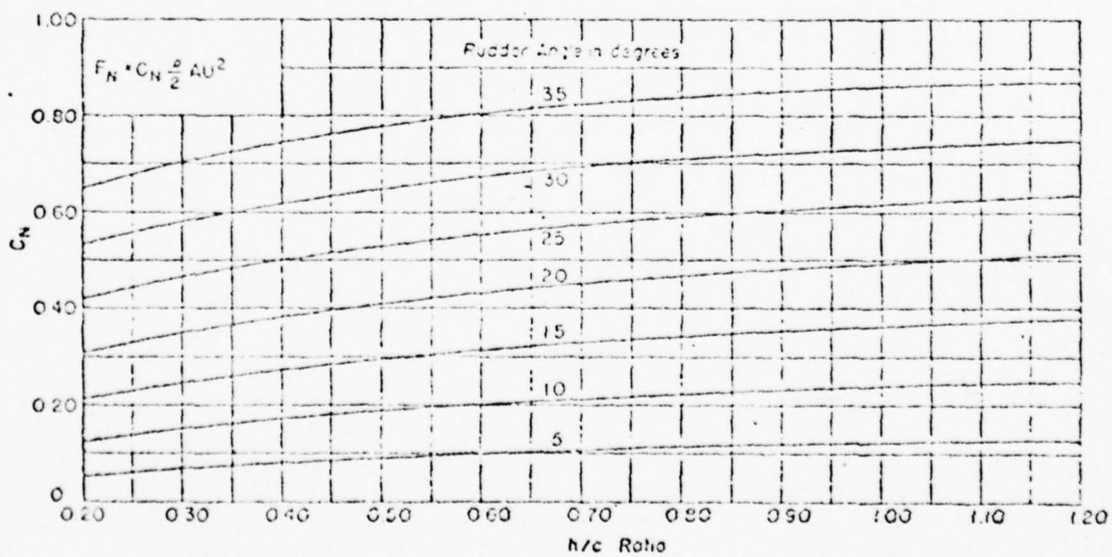


Figure 3 - Coefficient Curves for Normal Force

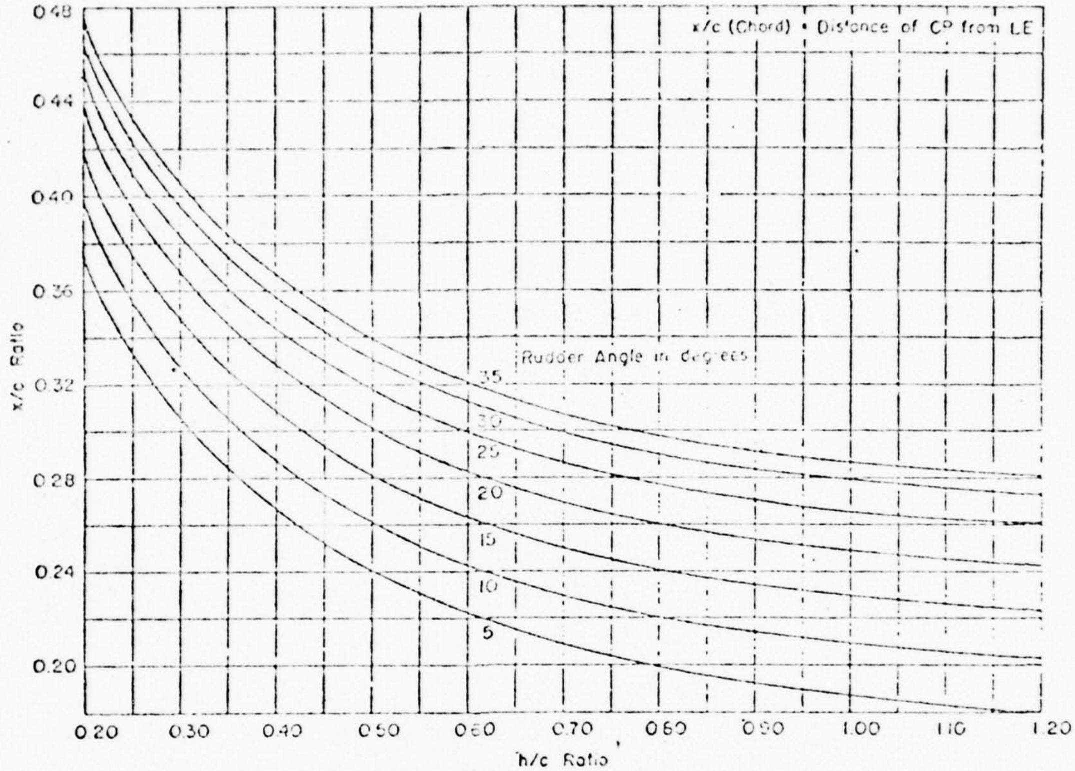
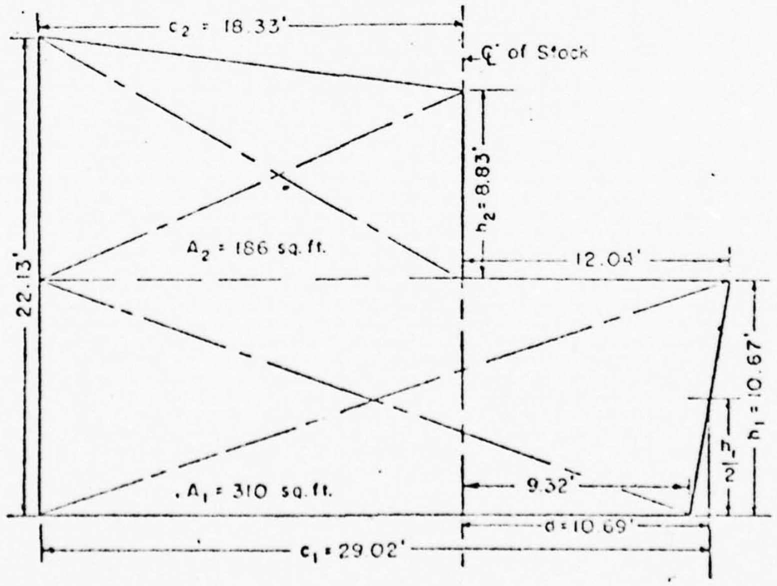


Figure 4 - Center of Pressure Curves



Area = 496 sq. ft.

Aspect Ratio, $\frac{(h_1 + h_2)^2}{A_1 + A_2} = 0.783$ $\quad \frac{h_1}{c_1} = 0.368$ $\quad \frac{h_2}{c_2} = 0.482$ $\quad$ Balance = 23 percent

Figure 5 - Principal Dimensions of CB 1 Rudder

TABLE 3

Rudder Torque Calculations USS Alaska (CB1)

Line	Rudder Angle Deg.	5	10	15	20	25	30	35
	Torque of Lower Portion							
1	C_N	.079	.167	.268	.375	.492	.612	.739
2	F_1 (kips)	68.7	145.4	233.0	326.0	428.0	532.0	643.0
3	x_1/c_1	.278	.298	.319	.339	.356	.369	.378
4	$x_1/c_1 - d/c_1$	.090	.070	.049	.029	.012	-.001	-.010
5	$x_1 - d$ (in.)	31.6	24.4	17.1	10.1	4.2	-0.3	-3.5
6	Q_1 (Kip-in.)	2,170	3,550	3,980	3,290	1,790	-160	-2,250
	Torque of Upper Portion							
7	C_N	.09	.187	.291	.416	.528	.649	.777
8	F_2 (kips)	47.0	97.6	152.0	217.0	275.5	338.5	405.5
9	x_2/c_2	-.245	-.266	-.287	-.306	-.323	-.336	-.345
10	x_2 (in.)	-53.9	-58.5	-63.2	-67.3	-71.1	-73.9	-75.0
11	Q_2 (Kip-in.)	-2,530	-5,170	-9,600	-14,600	-19,570	-25,000	-30,800
12	$Q_H = Q_1 + Q_2$	-360	-2,160	-5,620	-11,310	-17,780	-25,160	-33,050

Rudder Angle	5	10	15	20	25	30	35
			Total Torque				
Line 13 $F_N = F_R = F_1 + F_2$	115.7	243.0	385.0	543.0	703.5	870.5	1,048.5
14 Q_F (Kips-in.)	2.19	34.0	53.9	76.0	98.5	121.8	146.8
15 Q_A (kips-in.)	90.5	548.5	1,418.5	2,846.5	4,469	6,320	8,299
16 $Q = Q_H + Q_F + Q_A$	-267.2	-1,577	-5,566	-8,388	-13,212	-18,718	-24,604
17 $Q = Q_H - Q_F - Q_A$	-452	-2,742	-7,091	-14,232	-22,347	-31,601	-41,495

APPENDIX D

Computation of Stern Plane Forces and Torque

APPENDIX D - COMPUTATION OF STERN PLANE FORCES AND TORQUE (DEFINITION OF SYMBOLS USED SEE SHEETS 32 & 33)

GIVEN: A STERN PLANE AND STABILIZER AS SHOWN IN FIGURE 1 IS OUTSIDE OF THE PROPELLER RACE. THE ROOT & TIP SECTIONS ARE OF NACA0020 & NACA0010 RESPECTIVELY. THE MAXIMUM SHIP SPEED IS ASSUMED AT 28 KNOTS. SLEEVE BEARINGS ARE USED ON THE STERN PLANE STOCK. OTHER DIMENSIONS ARE:

1. Ω, SWEEP ANGLE OF $\frac{1}{4}$ CHORD = 23.55°
2. CHORD OF PLANE FORWARD OF STOCK C_b = 2.25'
3. CHORD OF PLANE AFT OF STOCK C_f = 4.67
4. ROOT CHORD C_R = 18.96'
5. TIP CHORD C_T = 11.25'
6. MEAN CHORD C_m = 15.10'
7. SPAN OF PLANE & STABILIZER S = 13.27'
8. SPAN OF FLAP AFT OF STOCK S_f = 14.42'
9. STERN PLANE & STABILIZER AREA A_{AR} = 201.90 FT² (GROSS)
10. STERN PLANE & STABILIZER AREA A_L = 194.86 FT² (NET)
11. AREA OF FLAP AFT OF STOCK A_f = 66.74 FT²

TO FIND: FORCES AND TORQUES THROUGHOUT THE RANGE OF FLAP ANGLES

THE STEP-BY-STEP PROCEDURE IS TABULATED BELOW:

LINE 3 — THE GEOMETRIC ASPECT RATIO R, IS $\frac{(SPAN)^2}{A_{AR}}$

$$= \frac{(13.27)^2}{201.90} = 0.873$$

FOR PLANE WITHOUT PUFFS FIN $AR_{e1} = 2 \times 0.872 = 1.746'$

FOR PLANE WITH PUFFS FIN OF 7 FT HIGH

$$h/b = \frac{7.0}{2 \times 13.27} = 0.264$$

FROM FIGURE 2, FOR $h/b = 0.264$ $\frac{AR_e}{AR_{e1}} = 1.46$

$$AR_e = 1.46 \times 1.746 = 2.55$$

LINE 4 — TAPER RATIO $\lambda = \frac{\text{TIP CHORD}}{\text{ROOT CHORD}} = \frac{11.25}{18.96} = 0.593$

LINES 5 & 6 — LIFT & HINGE-MOMENT COEFFICIENTS

COMPUTATION IS PRESENTED AS FOLLOW (LINE 7 IS CONTINUED ON SHT 16)

(1) OBTAIN ϵ/ϵ_{ell} VALUES FOR $\lambda = 0.593$ FROM FIG. 3.

$y/b/2$	ϵ/ϵ_{ell}
0	1.02
.2	.94
.4	.90
.6	.93
.8	1.08
.9	1.32
1.0	2.40

(2) OBTAIN LIFT SLOPE $C_{L\alpha}$ FOR $AR_e = 2.55$ AND $C_{\ell\alpha}$ FOR $AR_e = \infty$. FOR $C_{L\alpha}$ USE EB DIV. DESIGN CHARTS A-1407 & A-1409. THE SWEEP ANGLE EXTRAPOLATION FACTOR $= \frac{23.55 - 11.00}{11.00 - 0} = 1.14$

	$\Omega = 0°$	$\Omega = 11°$	Δ	1.14	$\Omega = 23.55°$
$C_{L10°}$	0.494	0.513	0.019	0.022	0.535

$$C_{L\alpha} = \frac{0.535}{10} = 0.0535 \text{ FOR } AR_e = 2.55$$

FROM NACA TR-460, $C_{\ell\alpha} = 0.1000$ FOR $AR_e = \infty$

(3) DETERMINE ϵ_{ell}

$$\epsilon_{ell} = \alpha_\delta \left(1 - \frac{C_{L\alpha}}{C_{\ell\alpha}}\right)\delta = \alpha_\delta\left(1 - \frac{0.0535}{0.1000}\right)\delta$$

$$\epsilon_{ell} = \alpha_\delta (0.465)\delta$$

(3.a) SUMMARIZE USEFULL DATA OF NACA 0015 AIRF

$c_f/c = 0.30$

1. PLAIN FLAP, FROM FIGURE 4

$c_b/c_f = 0.15$, $0.005c$ GAP

$\alpha_\delta = -0.460$

$c_{l\alpha} = 0.089$

2. BLUNT FLAP, 35% BALANCE. FROM FIG. 5.

$c_b/c_f = 0.35$, $0.005c$ GAP

$\alpha_\delta = -0.530$

$c_{l\alpha} = 0.079$

3 BLUNT FLAP 50% BALANCE, FROM FIG. 6

$c_b/c_f = 0.50$, $0.005c$ GAP

$\alpha_\delta = -0.650$

$c_{l\alpha} = 0.085$

(4) DETERMINE C_L/ϵ_{ell} FOR 15%, 35% & 50% BALANCE FL

$\alpha_\epsilon = \epsilon_{ell} = \alpha_\delta(0.465)\delta$

(4.a) $c_b/c_f = 0.15$, $\alpha_\delta = -0.460$

$\alpha_\epsilon = (-0.460)(0.465)\delta = -0.214\delta$

C_L FROM FIGURE 4.

$\delta°$	$\alpha_\epsilon°$	C_L	C_L/ϵ_{ell}	WEIGHTING FACTOR	$f\left(\frac{C_L}{\epsilon_{ell}}\right)$
0	0	—	-	0	—
5	-1.08	+.105	-.0972	1	-.0972
10	-2.14	+.245	-.1145	2	-.2290
15	-3.24	+.330	-.1018	3	-.3054
Σ				6	-.6316

$\therefore C_L/\epsilon_{ell} = \frac{1}{6} \times -.6316 = -0.1053$

(4.b) $c_b/c_f = 0.35, \quad \alpha_\delta = -0.530$

$$\alpha_\epsilon = (-0.530)(0.465)\delta = -0.246\,\delta$$

C_L FROM FIGURE 5

$\delta°$	$\alpha_\epsilon°$	C_L	C_L/ϵ_{ell}	WEIGHTING FACTOR	$f\left(\frac{C_L}{\epsilon_{ell}}\right)$
0	0	–	–	0	–
5	-1.23	+.130	-.1056	1	-.1056
10	-2.46	+.055	-.1036	2	-.2072
15	-3.69	+.350	-.0944	3	-.2847
Σ				6	-.5975

$$C_L/\epsilon_{ell} = \frac{1}{6} \times -.5975 = -.0994$$

(4.c) $c_b/c_f = 0.50 \quad \alpha_\delta = -0.650$

$$\alpha_\epsilon = (-0.650)(.465)\delta = -0.302\,\delta$$

C_L FROM FIGURE 6

$\delta°$	$\alpha_\epsilon°$	C_L	C_L/ϵ_{ell}	WEIGHTING FACTOR	$f\left(\frac{C_L}{\epsilon_{ell}}\right)$
0	0	–	–	0	–
5	-1.51	+.170	-.1125	1	-.1125
10	-3.02	+.285	-.0944	2	-.1888
15	-4.53	+.400	-.0884	3	-.2652
Σ				6	-.5655

$$C_L/\epsilon_{ell} = \frac{1}{6} \times -.5655 = 0.0943$$

(5) COMPUTE SLOPE C_L/ϵ FOR 15%, 35% & 5[illegible] BALANCE FLAPS

$$\frac{C_L}{\epsilon} = \frac{C_L}{\epsilon_{ell}} \div \frac{\epsilon}{\epsilon_{ell}}$$

FLAPS		15% BALANCE	35% BALANCE	50% BALANCE
REFERENCES		FIG. 4	FIG 5	FIG 6
C_L/ϵ_{e11} [FROM (4)]		1.053	·0994	·0943
$y/\frac{b}{2}$	ϵ/ϵ_{e11} [FROM (1)]	C_L/ϵ (SLOPE)		
0	1.02	-·1032	-.0975	-·0925
·2	·94	-·1120	-.1058	-·1003
·4	·90	-.1170	-·1104	-·1048
·6	·93	-.1132	-·1070	-·1014
·8	1.08	-.0975	-·0921	-·0873
·9	1.32	-·0797	-·0753	-·0715
1.0	2.40	-·0439	-·0414	-·0393

(6) USING SLOPES FROM (5), OBTAIN LIFT COEFFICIENTS AND HINGE-MOMENT COEFFICIENTS

(6.a) FROM FIGURE 4 FOR 15% BALANCE FLAP

$y/\frac{b}{2}$	$\delta = 0°$	5	10	15	20	25
	LIFT COEFFS - C_L					
·0	0	.105	·230	·330	.410	.470
·2	0	.110	.245	·345	·425	.490
·4	0	.115	.245	·345	.425	·490
·6	0	·115	.250	·350	.430	.500
·8	0	.105	·225	·320	·390	.460
·9	0	·110	·205	·290	·355	·415
1.0	0	·070	.145	·205	.255	·290
	HINGE-MOMENT COEFFS - C_{hf}					
0	—	-.029	-·054	-·110	-·171	-·231
·2	—	-.029	-.054	-·110	-·172	-·231
·4	—	-.030	-·054	-·110	-·172	-·231
·6	—	-.030	-.054	-·110	-·173	-·231
·8	—	-.029	-·053	-·109	-·170	-·230
·9	—	-.029	-·052	-·106	-·167	-·229
1.0	—	-.028	-.050	-.098	-.158	-.223

(6.b) FROM FIGURE 5 FOR 35% BALANCE FLAP

$y/\frac{b}{2}$	$\delta = 0°$	5	10	15	20	25
		LIFT COEFFS – C_L				
0	0	.125	.250	.355	.465	.435
.2	0	.130	.260	.370	.475	.445
.4	0	.135	.265	.380	.480	.455
.6	0	.130	.260	.370	.475	.445
.8	0	.125	.240	.350	.460	.425
.9	0	.110	.220	.315	.430	.390
1.0	0	.080	.150	.220	.310	.315
		HINGE-MOMENT COEFFS – C_{hf}				
0	—	–.014	–.023	–.046	–.120	–.187
.2	—	–.013	–.023	–.047	–.125	–.187
.4	—	–.013	–.024	–.048	–.127	–.187
.6	—	–.013	–.023	–.046	–.125	–.187
.8	—	–.014	–.023	–.046	–.107	–.187
.9	—	–.014	–.023	–.043	–.102	–.186
1.0	—	–.015	–.023	–.037	–.071	–.169

(6.c) FROM FIGURE 6 FOR 50% BALANCE FLAP

$y/\frac{b}{2}$	$\delta = 0°$	5	10	15	20	25
		LIFT COEFFS – C_L				
0	0	.155	.280	.405	.490	.465
.2	0	.165	.295	.420	.505	.470
.4	0	.170	.300	.425	.515	.475
.6	0	.165	.295	.420	.510	.470
.8	0	.155	.275	.395	.485	.460
.9	0	.140	.250	.360	.445	.435
1.0	0	.095	.170	.255	.315	.340
		HINGE-MOMENT COEFFS – C_{hf}				
0	—	+.007	+.021	+.045	+.020	–.088
.2	—	+.007	+.022	+.045	+.010	–.094
.4	—	+.008	+.022	+.045	+.007	–.099
.6	—	+.007	+.022	+.045	+.008	–.099
.8	—	+.007	+.020	+.045	+.024	–.085
.9	—	+.006	+.019	+.044	+.050	–.058
1.0	—	+.003	+.016	+.041	+.072	+.022

(7) CORRECTION FOR c_f/c (PRECEDING DATA IS $c_f/c = 0.30$)

$$C_T = 11.25'$$

$$C_R = 18.96'$$

$$\Delta_C = (18.96 - 11.25) \times \frac{y}{b/2} = 7.71 \frac{y}{b/2}$$

$$C = 18.96 - \Delta C.$$

LIFT COEFFICIENTS

α_δ & $\alpha_{\delta \cdot 30}$ ARE FROM FIG 7

EXPERIMENTAL DATA

$$\alpha_{\delta \cdot 30} = -0.575$$

$$c_f = 4.67$$

$$K_1 = \alpha_\delta / \alpha_{\delta \cdot 30} = \frac{\alpha_\delta}{-0.575}$$

HINGE-MOMENT COEFFICIENTS

$C_{hf\delta}$ & $C_{hf\delta \cdot 30}$ ARE FROM FIG

EXPERIMENTAL DATA

$$C_{hf\delta \cdot 30} = -0.00872.$$

$$K_2 = \frac{C_{hf\delta}}{C_{hf\delta \cdot 30}} = \frac{C_{hf\delta}}{-.00872}$$

COMPUTE K_1 AND K_2

$y/\frac{b}{2}$	ΔC	C	c_f/c	α_δ	K_1	$C_{hf\delta}$
0	0	18.96	.246	-.513	.892	-.0070[illegible]
.2	1.54	17.42	.268	-.540	.939	-.00[illegible]
.4	3.08	15.88	.294	-.570	.991	-.00[illegible]76
.6	4.63	14.33	.326	-.603	1.049	-.00[illegible]
.8	6.17	12.79	.365	-.645	1.122	-.00[illegible]
.9	6.94	12.02	.389	-.668	1.162	-.0[illegible]
1.0	7.71	11.25	.415	-.695	1.209	-.00757

(8) INTEGRATION FACTORS

1. LIFT COEFFICIENT FACTOR SPAN = 13.27' FOR STERN PLANE PLUS STABILIZER IS USED.

$$C_{L_{AVERAGE}} \times A_L = \sum_{n=0}^{TIP} \left[\tfrac{1}{3} \text{SPANWISE SPACING} \times (SM)_n \times (CHORD)_n \times (K_1)_n \times (C_L)_n\right]$$

$$\frac{\tfrac{1}{3}\text{ SPANWISE SPACING}}{A_L} = \frac{\tfrac{1}{3} \times .2 \times 13.27}{194.86} = .00454$$

$$C_{L_{AVERG}} = \sum_{n=0}^{TIP} \underbrace{\left[.00454 \times (SM)_n \times (C)_n \times (K_1)_n\right]}_{(FACTOR\ L)_n} \times (C_L)_n$$

2. HINGE-MOMENT COEFFICIENT FACTOR, SPAN = 14.42' FOR FLAP AFT OF STOCK IS USED.

$$C_{hf\,AVERAGE} \times A_f \times C_f = \sum_{n=0}^{TIP} \left[\tfrac{1}{3} \text{SPANWISE SPACING} \times (SM)_n \times (CHORD)_n^2 \times (K_2)_n \times (C_{hf})_n\right]$$

$$\frac{\tfrac{1}{3}\text{ SPANWISE SPACING}}{A_f \times C_f} = \frac{\tfrac{1}{3} \times .2 \times 14.42}{66.74 \times 4.67} = .003084$$

$$C_{hf\,AVERAGE} = \sum_{n=0}^{TIP} \underbrace{\left[.003084 \times (SM)_n \times (C_f)_n^2 \times (K_2)_n\right]}_{(FACTOR\ H)_n} \times (C_{hf})_n$$

COMPUTE $(FACTOR\ L)_n$ & $(FACTOR\ H)_n$

$y/\frac{b}{2}$	SM	C	K_1	FACTOR L	C_f	$(C_f)^2$	K_2	FACTOR H
0	1	18.96	.892	.0768	4.67	21.81	1.036	.0697
.2	4	17.42	.939	.2971			1.023	.2752
.4	2	15.88	.991	.1429			1.003	.1352
.6	4	14.33	1.049	.2730			.978	.2631
.8	3/2	12.79	1.122	.0977			.933	.0943
.9	2	12.02	1.162	.1268			.904	.1216
1.0	1/2	11.25	1.209	.0309	4.67	21.81	.868	.0292

(9) AVERAGE C_L & C_{hf}

(9.a) PLAIN FLAP - 15% BALANCE

$y/\frac{b}{2}$	$FACTOR_L$	LIFT COEFFICIENTS - (C_L FROM 6.a X $FACTOR_L$)					
		$\delta = 0°$	5	10	15	20	25
0	.0768	0	.00806	.01766	.02534	.03149	.03610
.2	.2971	0	.03268	.07279	.10250	.12627	.14558
.4	.1429	0	.01643	.03501	.04930	.06073	.07002
.6	.2730	0	.03140	.06825	.09555	.11739	.13650
.8	.0977	0	.01026	.02198	.03126	.03810	.04494
.9	.1268	0	.01268	.02599	.03677	.04501	.05262
1.0	.0309	0	.00216	.00448	.00633	.00783	.00896
AVERAGE C_L:		0	.11367	.24616	.34705	.42687	.49472

$y/\frac{b}{2}$	$FACTOR_H$	HINGE MOMENT COEFF - (C_{hf} FROM 6.a X $FACTOR_H$)					
		$\delta = 0°$	5	10	15	20	25
0	.0697	—	-.00202	-.00376	-.00767	-.01192	-.01610
.2	.2152	—	-.00798	-.01486	-.03027	-.04733	-.06357
.4	.1352	—	-.00406	-.00730	-.01487	-.02325	-.03123
.6	.2631	—	-.00789	-.01421	-.02894	-.04552	-.06078
.8	.0743	—	-.00273	-.00500	-.01028	-.01603	-.02169
.9	.1216	—	-.00353	-.00632	-.01289	-.02031	-.02785
1.0	.0292	—	-.00082	-.00146	-.00286	-.00461	-.00651
AVERAGE C_{hf}:		—	-.02903	-.0529	-.10778	-.16897	-.22773

(9·b) 35% BALANCE

$y/\frac{b}{2}$	$FACTOR_L$	LIFT COEFFICIENTS - (C_L FROM 6·b X $FACTOR_L$)					
		$\delta = 0°$	5	10	15	20	25
0	.0768	0	.0096	.0192	.0273	.0357	.0334
·2	·2971	0	.0386	.0772	.1099	.1411	.1322
·4	.1429	0	.0193	.0379	.0543	.0686	.0650
·6	·2730	0	.0355	.0710	.1010	.1297	.1215
·8	.0977	0	.0122	.0234	.0342	.0449	.0415
·9	.1268	0	.0139	.0279	.0399	.0545	.0495
1.0	.6309	0	.0025	.0046	.0069	.0096	.0097
AVERAGE C_L:		0	.1316	.2612	.3734	.4841	.4528

$y/\frac{b}{2}$	$FACTOR_H$	HINGE MOMENT COEFF - (C_{hf} FROM 6·b X $FACTOR_H$)					
		$\delta = 0°$	5	10	15	20	25
0	.0697	—	-.0010	-.0016	-.0032	-.0087	-.0130
·2	.2752	—	-.0036	-.0063	-.0129	-.0344	-.0515
·4	.1352	—	-.0018	-.0032	-.0065	-.0172	-.0253
·6	.2631	—	-.0034	-.0061	-.0121	-.0328	-.0492
·8	.0943	—	-.0013	-.0022	-.0043	-.0112	-.0176
·9	.1216	—	-.0017	-.0028	-.0052	-.0124	-.0226
1.0	.0292	—	-.0004	-.0007	-.0011	-.0021	-.0049
AVERAGE C_{hf}:		—	-.0132	-.0229	-.0453	-.1185	-.1841

(9.c) 50% BALANCE

$y/\frac{b}{2}$	$FACTOR_L$	LIFT COEFFICIENTS - (C_L FROM 6.C X $FACTOR_L$)					
		$\delta = 0°$	5	10	15	20	25
0	.0768	0	.0119	.0215	.0311	.0376	.0357
.2	.2971	0	.0490	.0876	.1248	.1500	.1396
.4	.1429	0	.0243	.0429	.0607	.0736	.0679
.6	.2730	0	.0450	.0805	.1147	.1392	.1283
.8	.0977	0	.0151	.0269	.0386	.0474	.0449
.9	.1268	0	.0178	.0317	.0456	.0564	.0552
1.0	.0309	0	.0029	.0053	.0079	.0097	.0105
AVERAGE C_L:		0	.1660	.2964	.4234	.5139	.4821

$y/\frac{b}{2}$	$FACTOR_H$	HINGE MOMENT COEFF - (C_{hf} FROM 6.C X $FACTOR_H$)					
		$\delta = 0°$	5	10	15	20	25
0	.0697	—	+.0005	+.0015	+.0031	+.0014	-.0061
.2	.2752	—	+.0019	+.0061	+.0124	+.0028	-.0259
.4	.1352	—	+.0011	+.0030	+.0061	+.0009	-.0134
.6	.2631	—	+.0018	+.0058	+.0118	+.0021	-.0260
.8	.0943	—	+.0007	+.0019	+.0042	+.0023	-.0080
.9	.1216	—	+.0007	+.0023	+.0054	+.0061	-.0070
1.0	.0292	—	+.0001	+.0005	+.0012	+.0021	+.0006
AVERAGE C_{hf}:		—	+.0001	+.0211	+.0442	+.0177	-.0858

(10) STREALINE CURVATURE CORRECTION TO AVERAGE HINGE-MOMENT COEFFICIENTS

(10.a) PLAIN FLAP - 15% BALANCE

FROM DATA IN (3.a)

$\alpha_{\delta \cdot 30} = -0.460$

$C_{l\alpha} = 0.089$

FROM TABLE IN (7)

AT $y/\frac{b}{2} = 0.6$ $\quad c_e/c = c_f/c = 0.326 \quad K_1 = 1.049$

$\alpha_{\delta \cdot 326} = \alpha_{\delta \cdot 30} \times K_1 = -0.460 \times 1.049 = -0.483$

$A = AR_e = 2.55 \quad A\left(\frac{0.1}{C_{l\alpha}}\right) = \frac{2.55 \times .1}{0.089} = 2.87$

FROM FIG 9 FOR $c_e/c = 0.326$ & $A\left(\frac{0.1}{C_{l\alpha}}\right) = 2.87$

$$(\Delta C_{h_f})_{sc} = \frac{(c_e/c)^2}{F} \frac{1}{\eta \, C_{l_\delta}} (A)(A+4.21) = 0.528$$

WHERE $\eta = 1 - 0.0005\,\phi^2$

$\phi = 18^\circ$ (TRAILING EDGE ANGLE NACA0015)

$\eta = 1 - 0.0005(18)^2 = 0.838$

$C_{l_\delta} = C_{l\alpha} \times \alpha_\delta = (0.089)(-0.483) = -.043$

FROM FIGURE 10, FOR $c_e/c = 0.326$ & $c_b/c_e = 0.15$

$$\frac{F}{(c_e/c)^2} = 1.082$$

$$(\Delta C_{h_f})_{sc} = 0.528 \frac{F}{(c_e/c)^2} \eta \cdot C_{l_\delta} \frac{1}{A(A+4.21)}$$

$$= \frac{0.528 \times 1.082 \times 0.838\,(-0.0430)}{2.55(2.55+4.21)} = -.001194$$

$$(\Delta C_{h_f})_{sc}\,\delta = -.001194\,\delta$$

(10.b) FLAP – 35% BALANCE

FROM DATA IN (3.a)

$\alpha_{\delta \cdot 30} = -0.530$

$C_{l\alpha} = 0.079$

FROM TABLE IN (7)

AT $y/\frac{b}{2} = 0.6$ $\quad c_e/c = c_f/c = 0.326$ $\quad K_1 = 1.049$

$\alpha_{\delta \cdot 326} = \alpha_{\delta \cdot 30} \times K_1 = -0.530 \times 1.049 = -0.556$

$A = AR_e = 2.55, \quad A\left(\frac{0.1}{C_{l\alpha}}\right) = \frac{2.55 \times .1}{0.079} = 3.23$

FROM FIG 9 FOR $c_e/c = 0.326$ & $A\left(\frac{0.1}{C_{l\alpha}}\right) = 3.23$

$$(\Delta C_{h_f})_{sc} = \frac{(c_e/c)^2}{F} \frac{1}{\eta C_{l_\delta}} (A)(A+4.21) = 0.549$$

WHERE $\eta = 0.838$

$C_{l_\delta} = C_{l\alpha} \times \alpha_\delta = (0.079)(-0.556) = -0.0439$

FROM FIG 10 FOR $c_e/c = 0.326$ & $c_b/c_e = 0.35$

$$(\Delta C_{h_f})_{sc} = 0.549 \frac{F}{(c_e/c)^2} \cdot \eta \cdot C_{l_\delta} \frac{1}{A(A+4.21)}$$

$$= \frac{0.549 \times 0.890 \times 0.838(-0.0439)}{2.55(6.76)} = -0.001042$$

$(\Delta C_{h_f})_{sc}\,\delta = -0.001042\,\delta$

(10.c) 50% BALANCE

FROM DATA IN (3.a)

$\alpha_{\delta.30} = -0.650$

$C_{\ell\alpha} = 0.085$

FROM TABLE IN (7)

AT $y/b/2 = 0.6$ $\quad Ce/c = Cf/c = 0.326 \quad K_1 = 1.049$

$\alpha_{\delta.326} = \alpha_{\delta.30} \times K_1 = -0.650 \times 1.049 = -0.682$

$A = AR_e = 2.55 \quad A\left(\frac{0.1}{C_{\ell\alpha}}\right) = \frac{2.55 \times .1}{0.085} = 3.00$

FROM FIGURE 9 FOR $Ce/c = 0.326$ & $A\left(\frac{0.1}{C_{\ell\alpha}}\right) = 3.00$

$(\Delta C_{\ell f})_{sc} = \frac{(Ce/c)^2}{F} \frac{1}{\eta \, C_{\ell\delta}} (A)(A+4.21) = 0.535$

WHERE $\eta = 0.838$

$C_{\ell\delta} = C_{\ell\alpha} \times \alpha_\delta = (0.085)(-0.682) = -0.058$

FROM FIG. 10 FOR $Ce/c = 0.326$ & $Cb/C_\ell = 0.50$

$\frac{F}{(Ce/c)^2} = 0.632$

$(\Delta C_{\ell f})_{sc} = (0.535) \cdot \frac{F}{(Ce/c)^2} \cdot \eta \cdot C_{\ell\delta} \frac{1}{A(A+4.21)}$

$= \frac{0.535 \times 0.632 \times 0.838 (-0.0580)}{2.55 \times 6.76} = -0.000953$

$(\Delta C_{\ell f})_{sc} \, \delta = -0.000953 \, \delta$

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DEVELOPMENT OF A TECHNICAL PRACTICE FOR RUDDERS AND DIVING PLAN--ETC(U)

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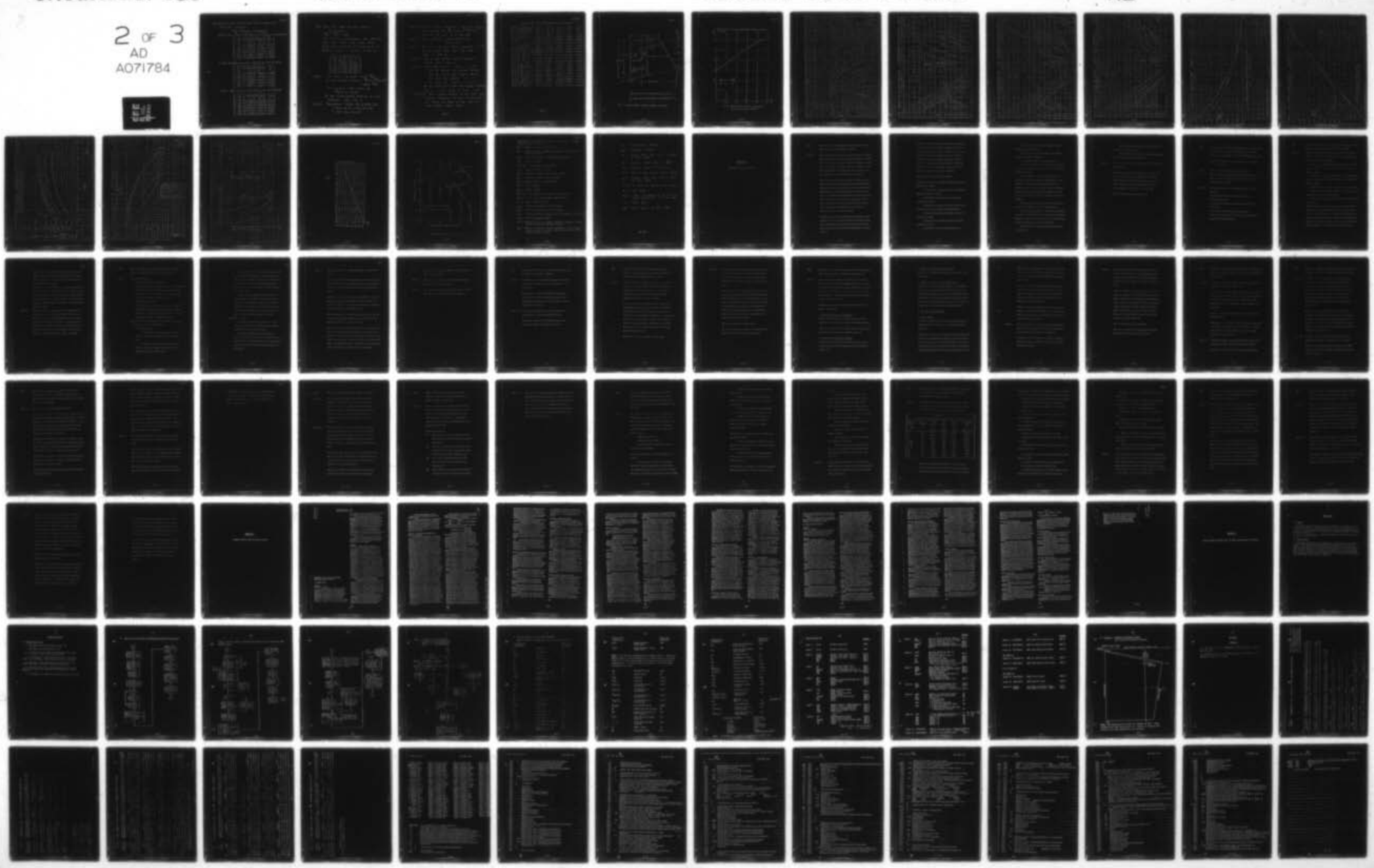

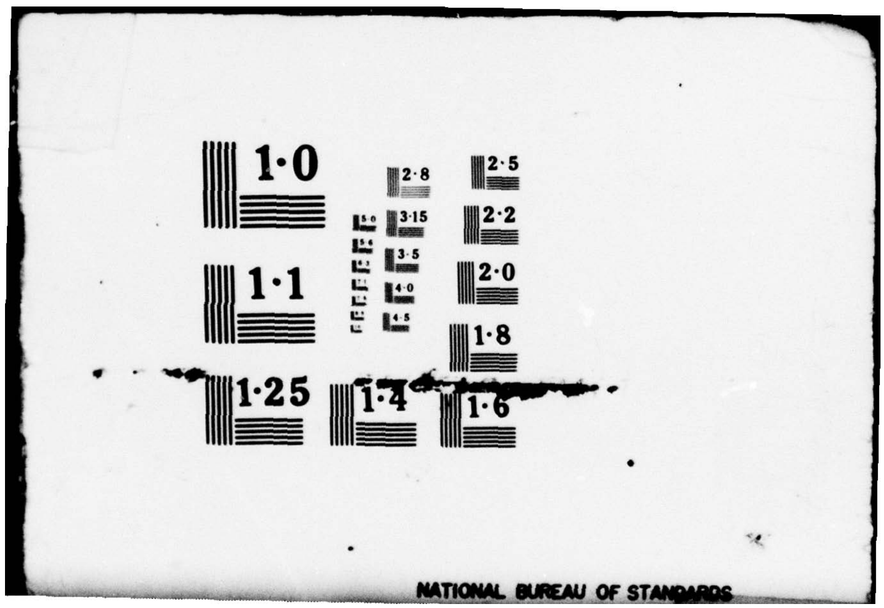
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NATIONAL BUREAU OF STANDARDS

(11) HINGE-MOMENT COEFFICIENTS WITH STREAMLINE CURVATURE CORRECTION

$$C_{hf} = (C_{hf})_{unc} - (\Delta C_{hf})_{sc}\,\delta$$

(11·a) PLAIN FLAP - 15% BALANCE, $(\Delta C_{hf})_{sc}\,\delta = -0.001194\,\delta$

$\delta°$	$(C_{hf})_{unc}$	$(\Delta C_{hf})_{sc}\,\delta$	C_{hf}
0	—	0	—
5	−.0290	−.0060	−.0230
10	−.0529	−.0119	−.0410
15	−.1078	−.0179	−.0899
20	−.1690	−.0239	−.1451
25	−.2277	−.0299	−.1979

(11·b) 35% BALANCE FLAP, $(\Delta C_{hf})_{sc}\,\delta = -0.001042\,\delta$

$\delta°$	$(C_{hf})_{unc}$	$(\Delta C_{hf})_{sc}\,\delta$	C_{hf}
0	—	0	—
5	−.0132	−.0052	−.0080
10	−.0229	−.0104	−.0125
15	−.0453	−.0156	−.0297
20	−.1185	−.0208	−.0977
25	−.1841	−.0261	−.1580

(11.c) 50% BALANCE FLAP $(\Delta C_{hf})_{sc}\,\delta = -0.0009538\,\delta$

$\delta°$	$(C_{hf})_{unc}$	$(\Delta C_{hf})_{sc}\,\delta$	C_{hf}
0	—	0	—
5	+.0068	−.0048	+.0116
10	+.0211	−.0095	+.0306
15	+.0442	−.0143	+.0585
20	+.0177	−.0191	+.0368
25	−.0858	−.0238	−.0620

(12) TOTAL LIFT FORCE AND HINGE MOMENT COEFFICIENTS

$$C_b/C_f = \frac{2.25}{4.67} = 0.482$$

THE FOLLOWING COEFFICIENTS ARE OBTAINED FROM CROSS PLOTS USING DATA FROM (9.a), (9.b) AND (9.c); AND (11.a), (11.b) AND (11.c) AS SHOWN IN FIGURES 11 AND 12.

δ	C_L	C_{hf}
0°	0	—
5°	0.162	+.0088
10°	0.286	+.0232
15°	0.414	+.0448
20°	0.512	+.0042
25°	0.472	-.0792

LINE 7 SHIP SPEED = 28 KNOTS = 47.26 FT./SEC.

q = UNIT DYNAMIC PRESSURE = $\frac{\rho}{2} v^2 = \frac{1.99}{2}(47.26)^2$

$= 2223$ LB./FT.^{3}

LIFT $= q A_L C_L = 2223 \times 194.86 \times C_L$

$= 433.2\ C_L$ (KIPS)

TO GET LINE 19, MULTIPLY 433.2 KIPS BY LIFT COEFFICIENT FROM LINE 5.

LINE 8 HYDRODYNAMIC TORQUE $Q_H = q A_f C_f C_{hf}$

$= 2223 \times 66.74 \times 4.67 \times 12 \times C_{hf}$

$= 8314\ C_{hf}$ (KIP-IN)

LINE 9-12 NORMAL FORCE COEFFICIENT $C_{Nf} = n_o C_L - n\,\delta_{rad}$

FROM FIGURE 13 FOR $c_f/c = 0.326$ AT $y/\frac{b}{2} = 0.6$

$n_o = 0.27$ $n = -1.72$ & C_L FROM (12)

LINE 13 $F_{Nf} = q\,A_p\,C_{Nf} = 2223 \times 94.17 \times C_{Nf}$

$= 209.3\ C_{Nf}$

LINE 14 THIS IS AN ARBITRARY ERROR ALLOWANCE OF 6% OF FLAP CHORD. FROM FIG. 1 THE FLAP CHORD IS 4.67 FT.

LINE 15 THIS IS THE TORQUE ERROR ALLOWANCE LINE 14 TIMES LINE 13.

LINE 16 $Q_F = F_{Nf} \times \mu \times r$ ASSUME $\mu = 0.02$

$0.55\ F_{Nf}$ APPLIED AT OUTBOARD BEARING

$0.45\ F_{Nf}$ APPLIED AT INBOARD BEARING

DIA. OVER OB. SLEEVE 4" + 1" = 5"

DIA. OVER IB. SLEEVE 10" + 1" = 11"

$Q_F = F_{Nf} \times 0.20\ (0.55 \times 2.50 + 0.45 \times 5.50) = 0.770\ F_{Nf}$

LINE 16 IS THEN LINE 13 TIMES 0.770

LINES 17-20 THESE INVOLVE ADDITION OF THE ERROR AND FRICTION ALLOWANCE TO GET AN ENVELOPE OF TORQUE AS SHOWN IN THE PLOT OF FINAL TORQUE CURVE FIG. 14.

TABULATION OF CALCULATIONS FOR APPENDIX D

LINE						
1	FLAP ANGLE DEG	5	10	15	20	25
2	ANGLE OF FLOW RELATIVE TO FLAP°	5	10	15	20	25
3	EFFECTIVE ASPECT RATIO	2.55	2.55	2.55	2.55	2.55
4	TAPER RATIO	0.594	0.594	0.594	0.594	0.594
5	C_L	0.162	0.286	0.414	0.512	0.472
6	C_{hf}	+0.0088	+0.0232	+0.0448	+0.0042	-0.0792
7	NORMAL FORCE F_N, KIPS	70.2	123.9	179.3	221.8	204.5
8	Q_H, KIP-IN	+73.2	+192.9	+372.5	+34.9	-658.5
9	δ RAD	0.0873	0.1745	0.2618	0.3491	0.4363
10	$\eta_o C_L$	0.0405	0.0786	0.1120	0.1380	0.1301
11	$-\eta\, \delta$ RAD	0.1502	0.3001	0.4503	0.6005	0.7504
12	C_{Nf}	0.1907	0.3787	0.5623	0.7385	0.8805
13	F_{Nf}, KIPS	39.9	79.3	117.7	154.6	184.3
14	ALLOWABLE TORQUE ARM, IN	3.36	3.36	3.36	3.36	3.36
15	Q_E, KIP-IN	134.1	266.4	395.5	519.5	619.2
16	Q_F, KIP-IN	30.7	61.1	90.6	119.0	141.9
17	$Q_H + Q_E$ KIP-IN	+207.3	+459.3	+768.0	+554.4	-39.3
18	$Q_H - Q_E$ KIP-IN	-60.9	-73.5	-23.0	-484.6	-1277.7
19	$Q_H + Q_E + Q_F$ KIP-IN	+238.0	+520.4	+858.6	+673.0	+102.6
20	$Q_H - Q_E - Q_F$ KIP-IN	-91.6	-135.1	-113.6	-603.6	-1419.6

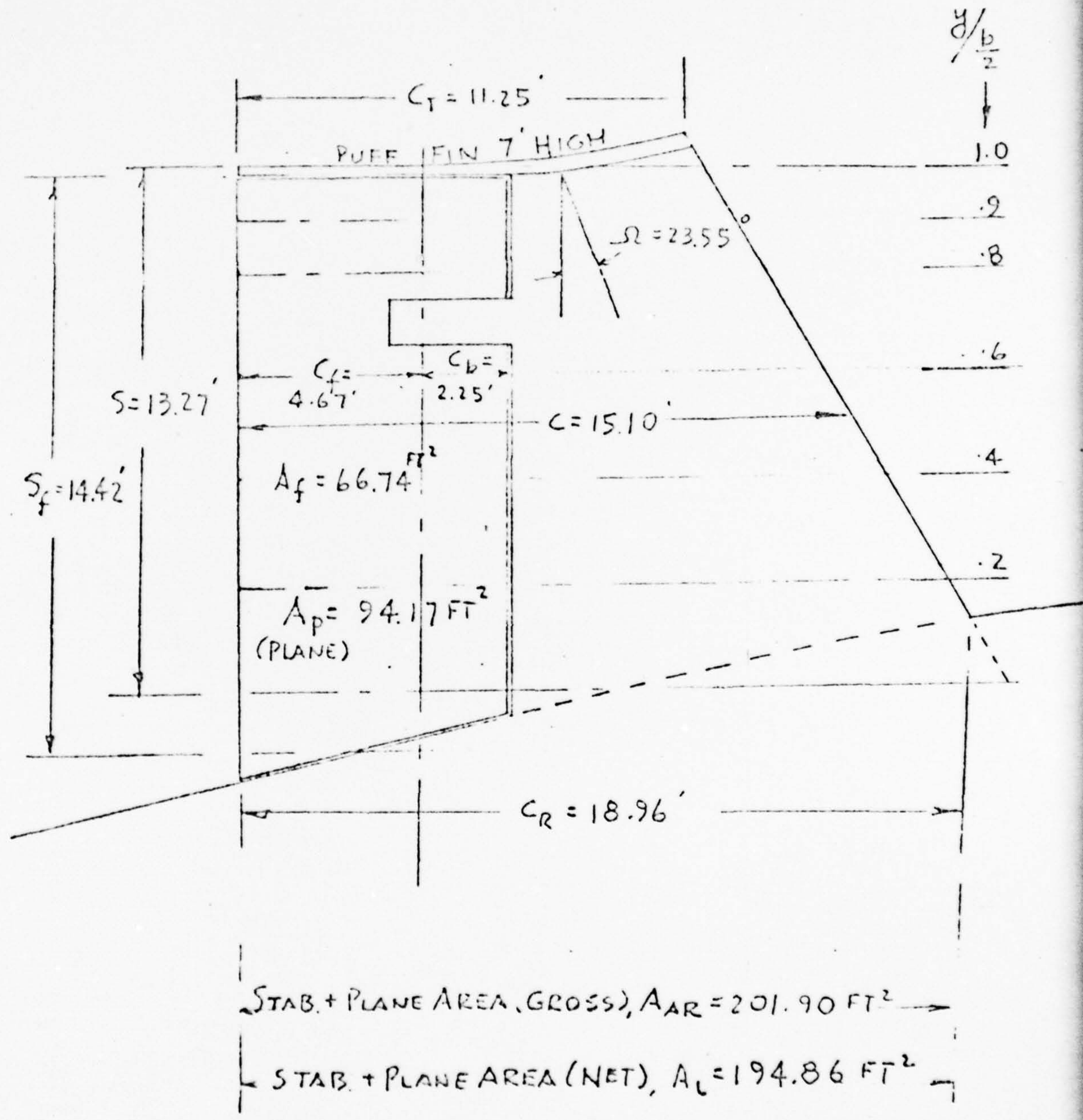


FIG. 1 STABILIZER & STERN PLANE OUTLINE

FROM HOERNER'S FLUID-DYNAMIC DRAG CHAPTER 7
FIG 15a

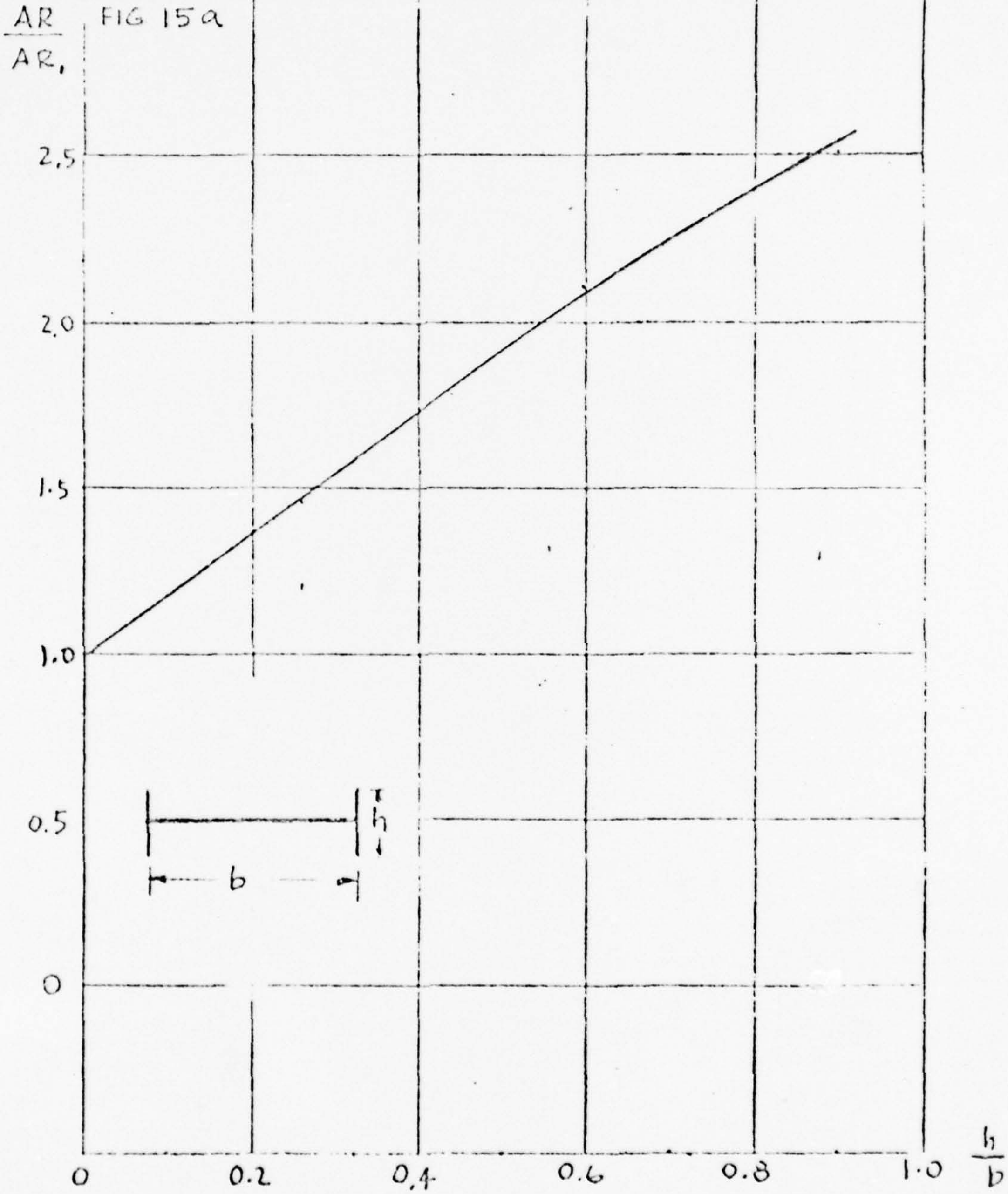


FIG. 2 EFFECTIVE ASPECT RATIO OF WING WITH END PLATES

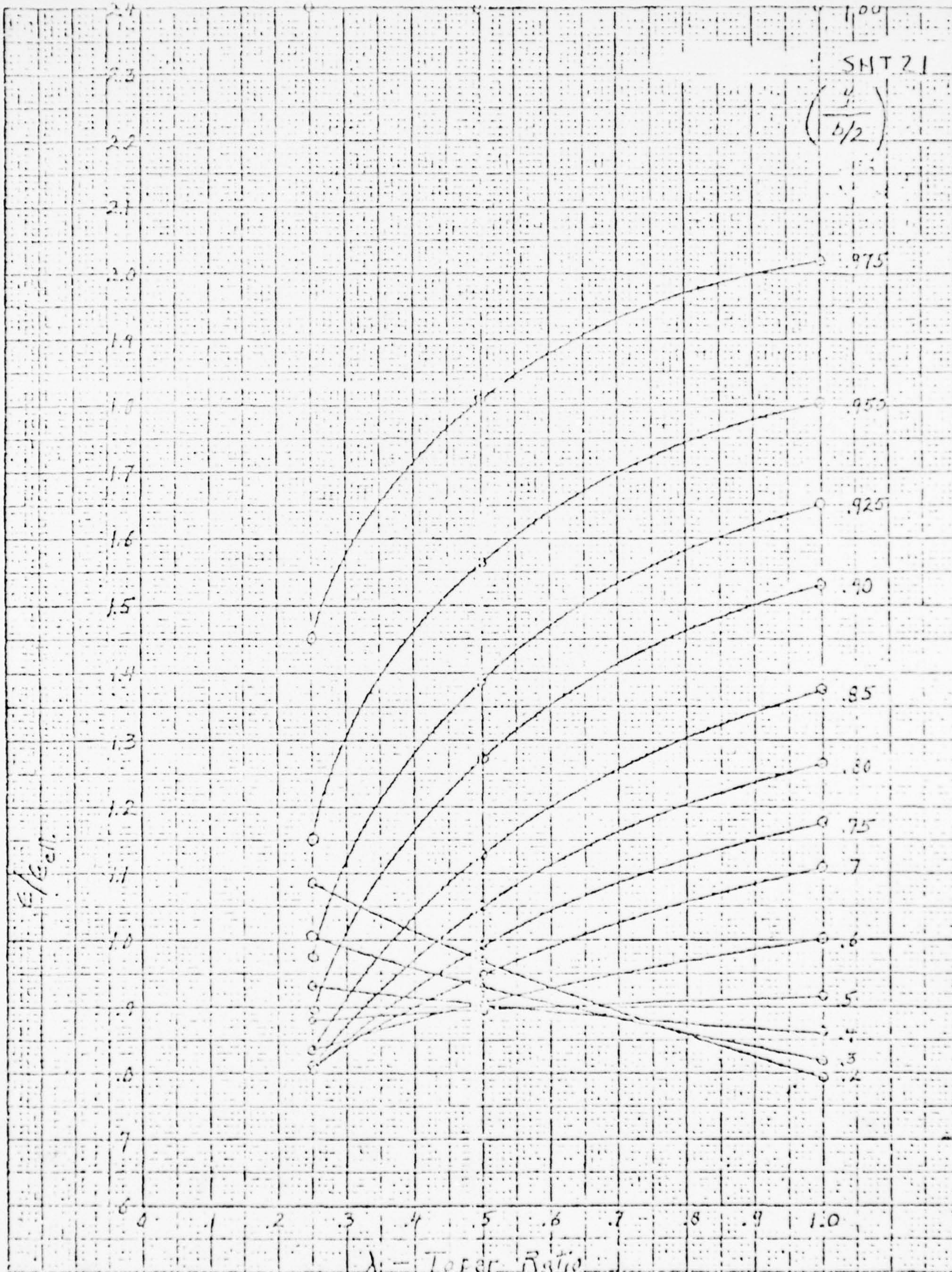
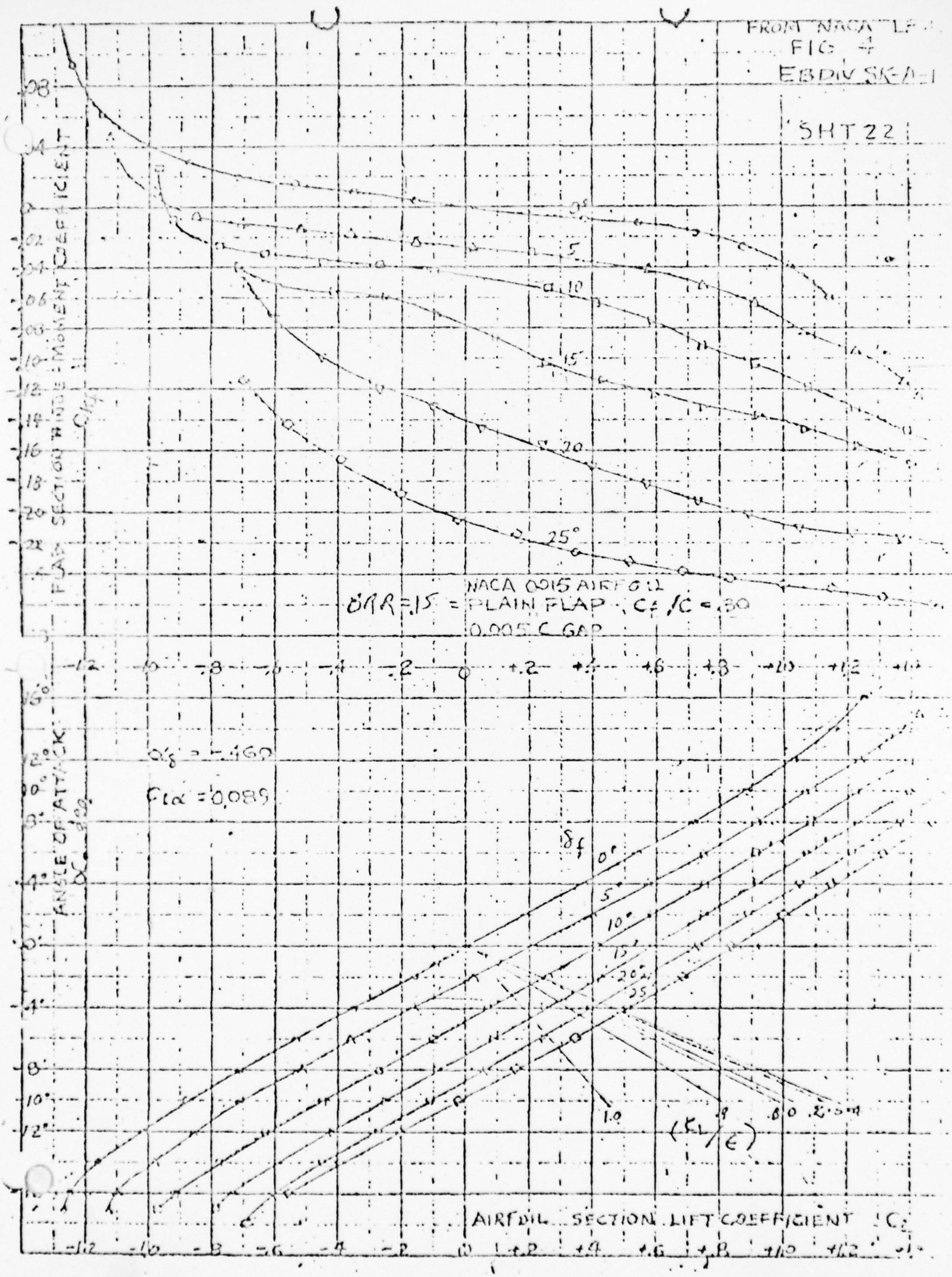
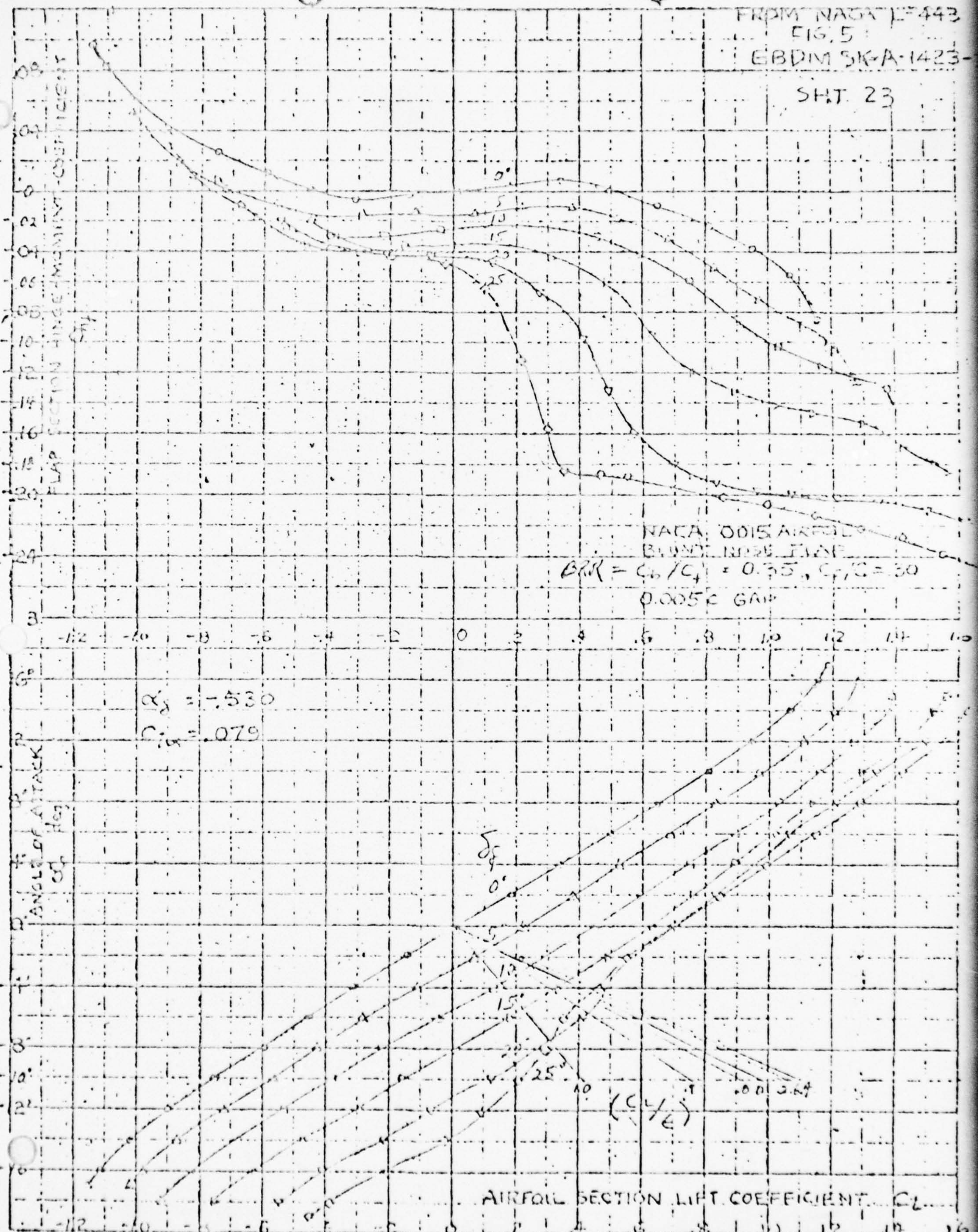


FIG 3 E/E_{ell} Vs λ



FROM NACA LF...
FIG 4
EBDIV SK-A-1
SHT 22
FLAP SECTION HINGE MOMENT COEFFICIENT C_{hf}
ANGLE OF ATTACK α
NACA 0015 AIRFOIL
BRR = .15 = PLAIN FLAP, C_f/C = .30
0.005 C GAP
α_δ = -.460
$C_{l\alpha}$ = 0.089
δ_f
0°
5°
10°
15°
20°
25°
(K_L/ϵ)
AIRFOIL SECTION LIFT COEFFICIENT C_l

FROM NACA L-443
FIG. 5
EBDM SK-A-1423-
SHT. 23



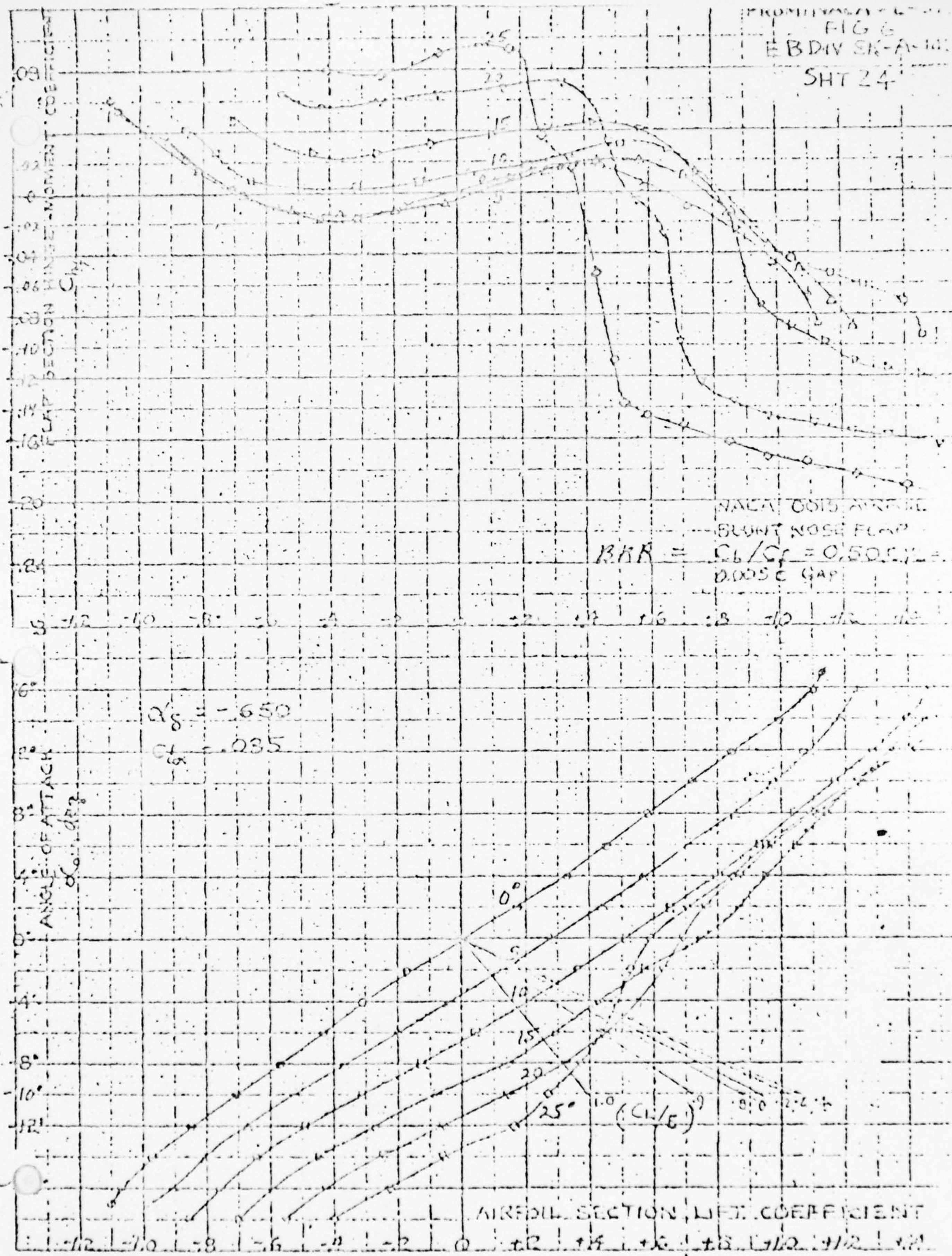


FIG 6
EB DIV SK-A-
SHT 24
FLAP SECTION HINGE MOMENT COEFFICIENT
C_h
NACA 0015 AIRFOIL
BLUNT NOSE FLAP
BKR = C_b/C_f = 0.50
0.005 C GAP
ANGLE OF ATTACK α_o, deg
α_δ = -.650
C_{l_α} = .035
0°
5
10
15
20
25°
(C_L/δ)
AIRFOIL SECTION LIFT COEFFICIENT

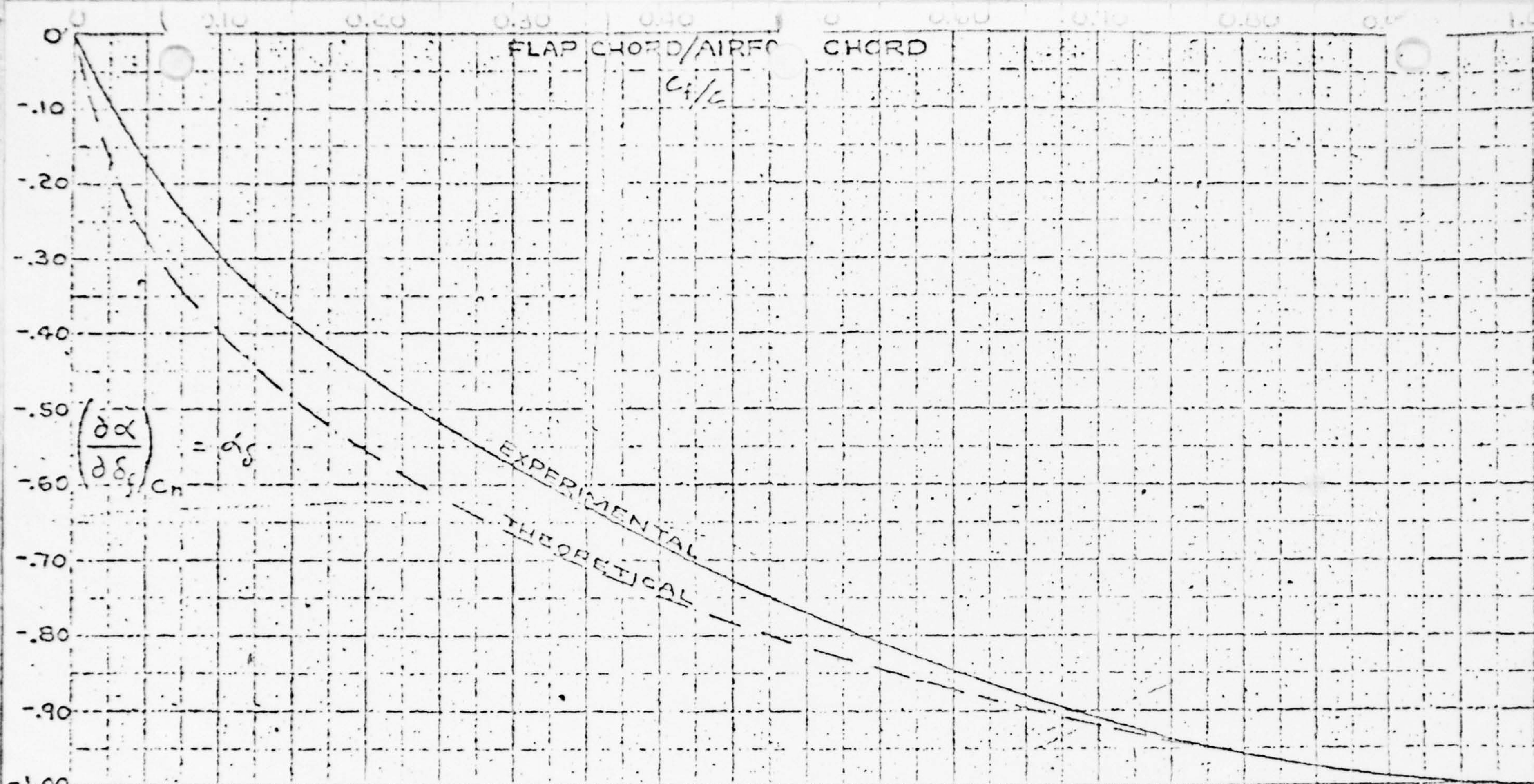


FIG. 7 VARIATION OF $(\partial\alpha/\partial\delta_f)_{C_h}$ WITH C_f/C FOR NACA 0009 AIRFOIL

SHT 25

FROM NACA REPORT 721, Fig 11

SK.A-1192 SHEET 1

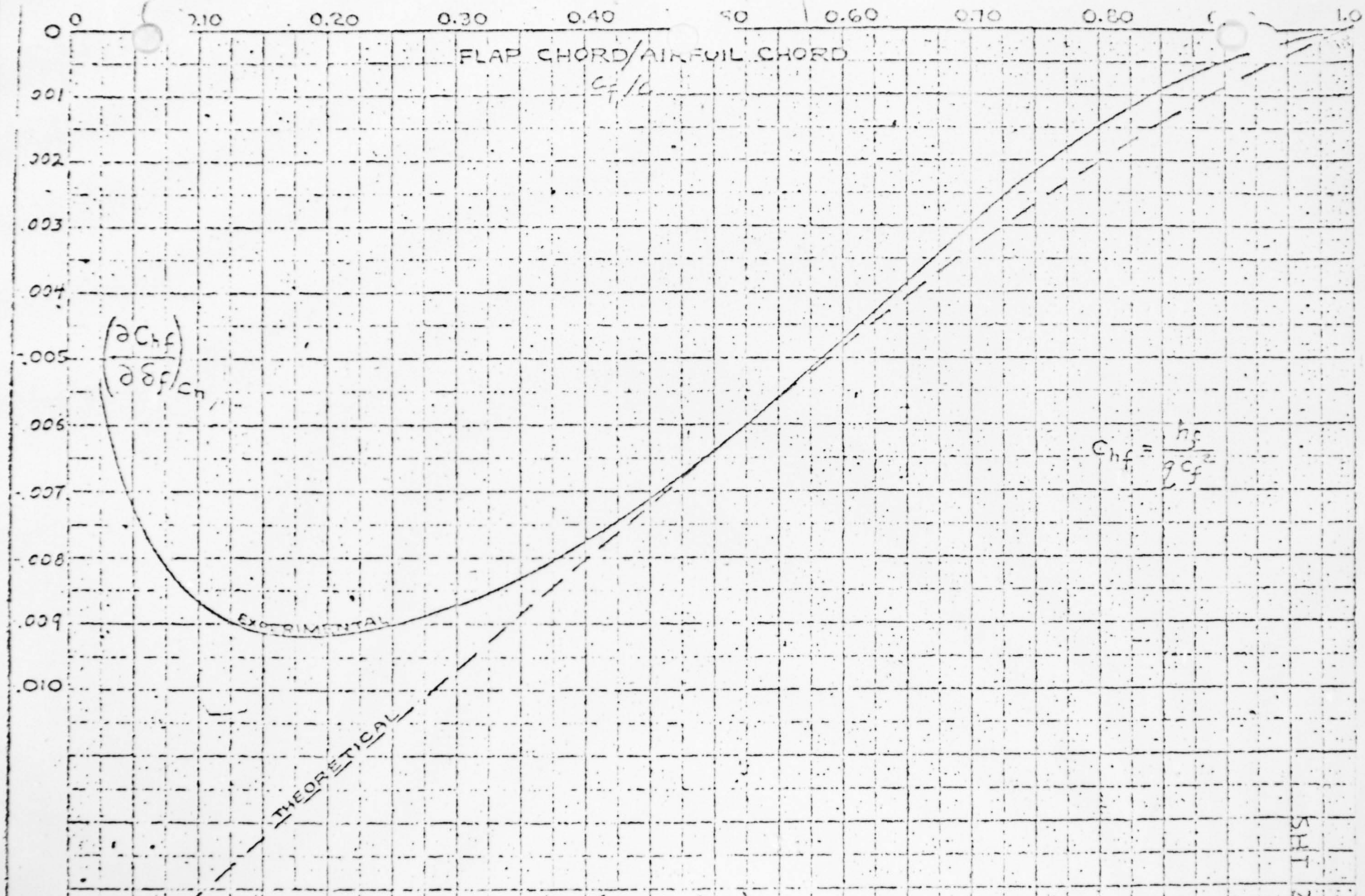


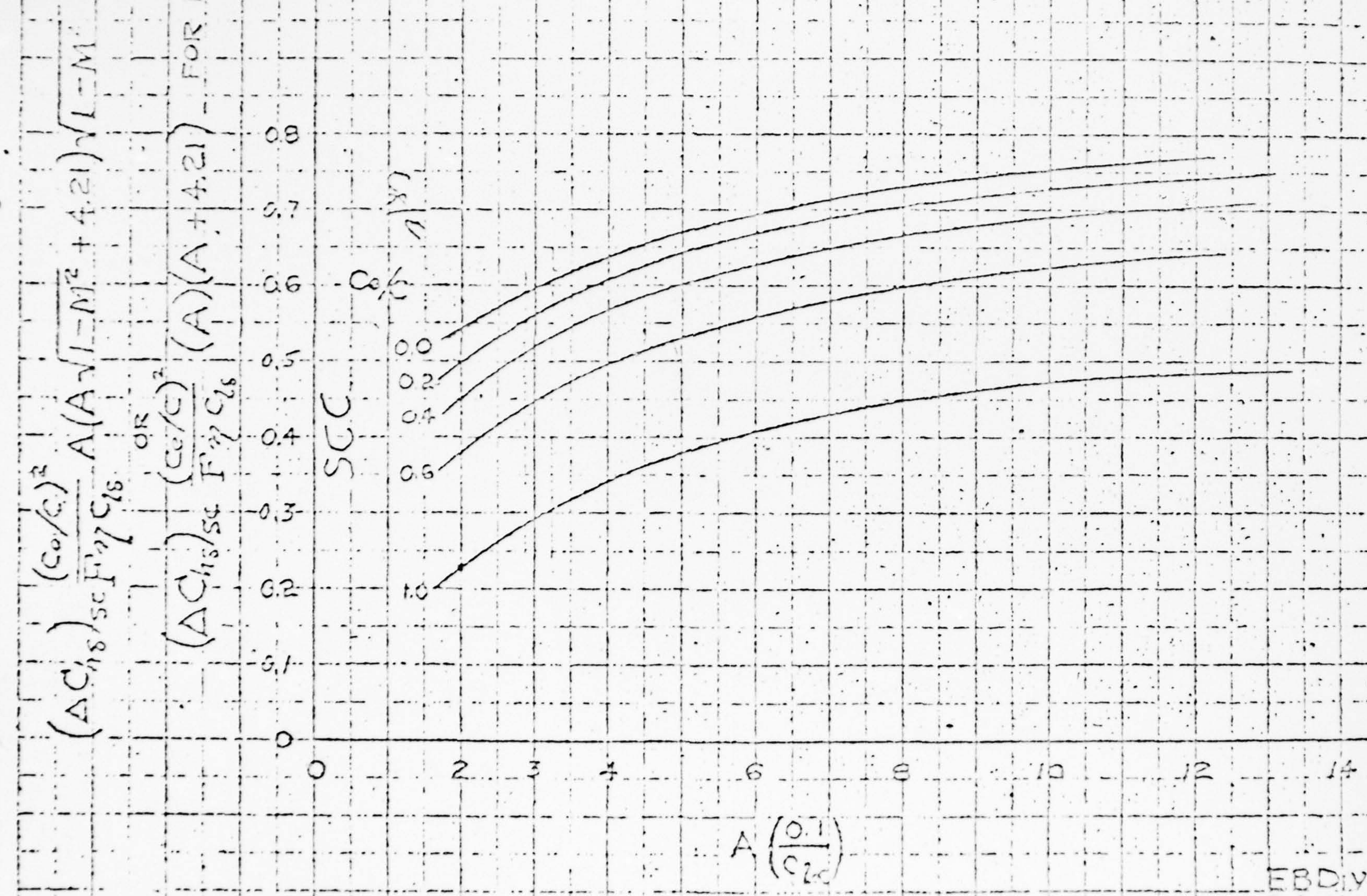
FIG. 8. VARIATION OF $(\partial c_{hf}/\partial \delta_f)_{c_n}$ WITH c_f/c FOR NACA 0009 AIRFOIL

SK-A-1192 SHEET 3

FROM NACA REPORT 721, Fig. 21

NACA TR-91
Fig. 9

CHART BASED ON LIFTING-SURFACE THEORY FOR THE DETERMINATION OF THE INCREMENT OF HINGE-MOMENT COEFFICIENT CAUSED BY INDUCED ELLIPTIC CHORDWISE LOADING



SHT 27

EB DIV
SK A-1422-1

NACA TR-91
Fig. 10.
SHT. 28

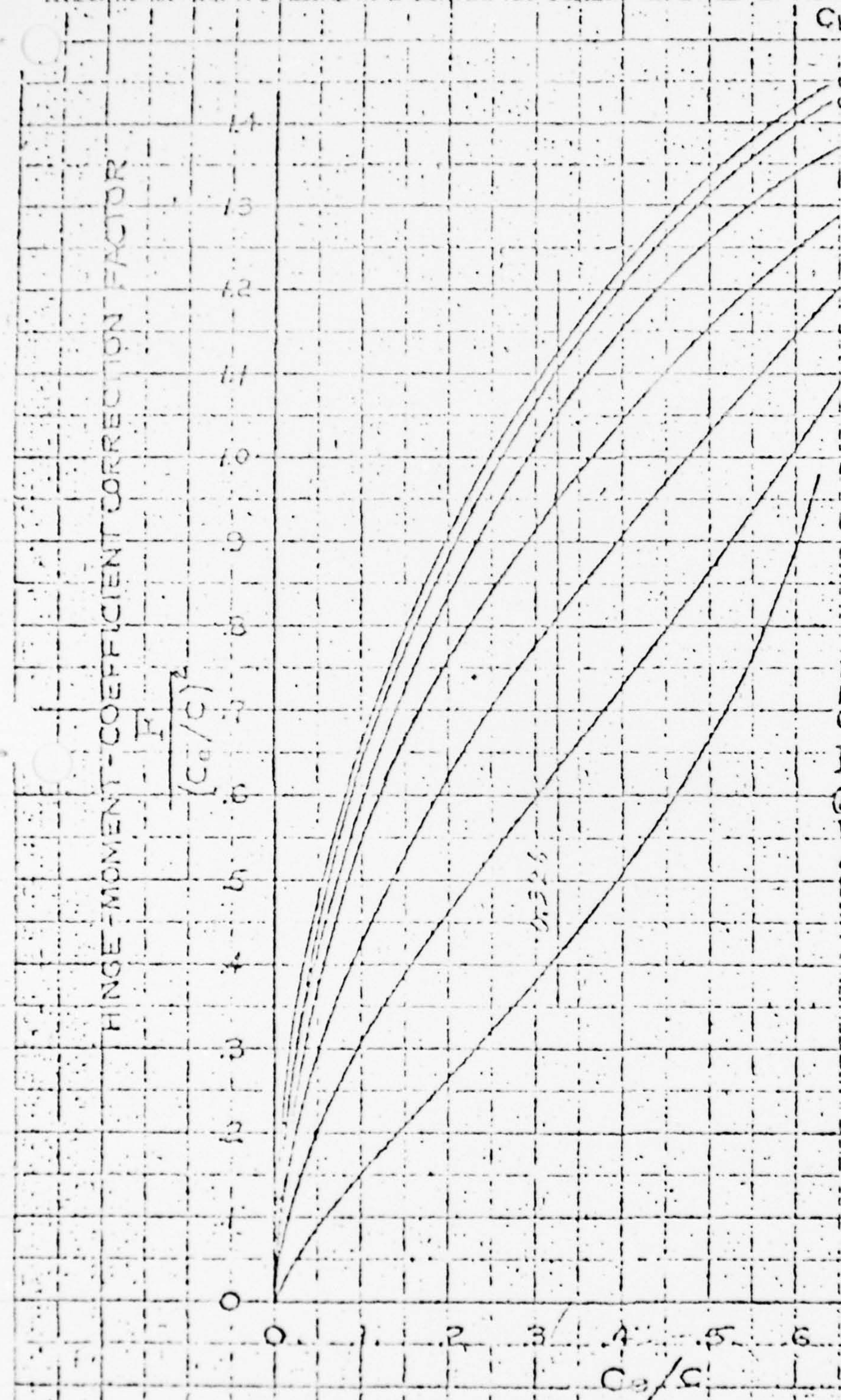


CHART BASED ON THIN AIRFOIL THEORY FOR EVALUATION OF THE HINGE-MOMENT-COEFFICIENT CORRECTION FACTOR $F/(C_e/C)^2$ FOR ELEVATORS.

(a) PLAIN NOSE AND EXTERNAL-OVERHANG AERODYNAMIC BALANCES.

EBDiv.
SK A-14...

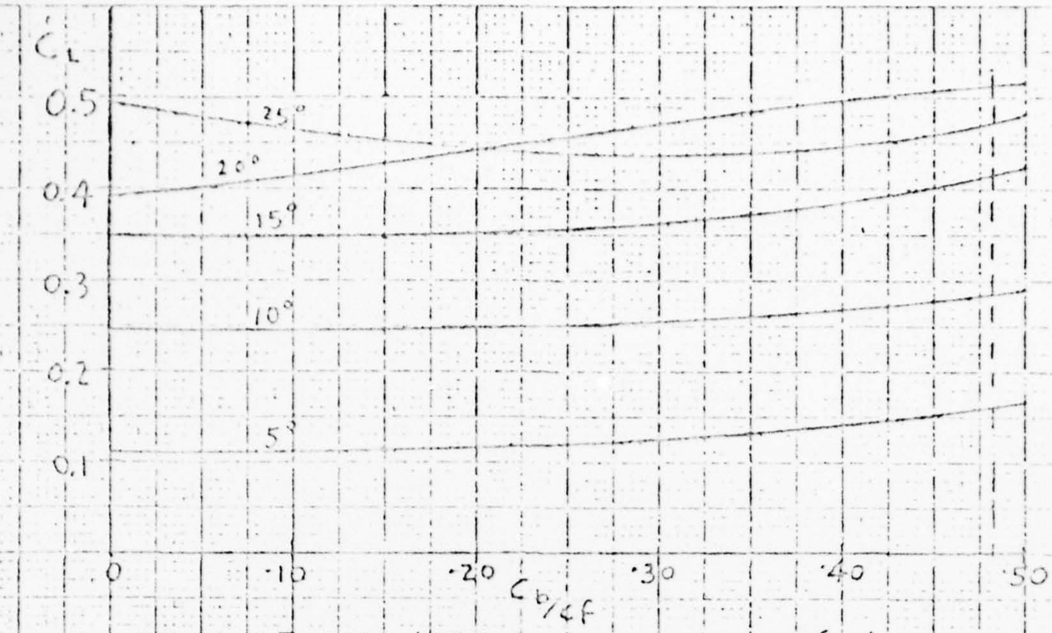


FIG 11. LIFT COEFFICIENT Vs C_b/C_f FOR VARIOUS PLANE ANGLE

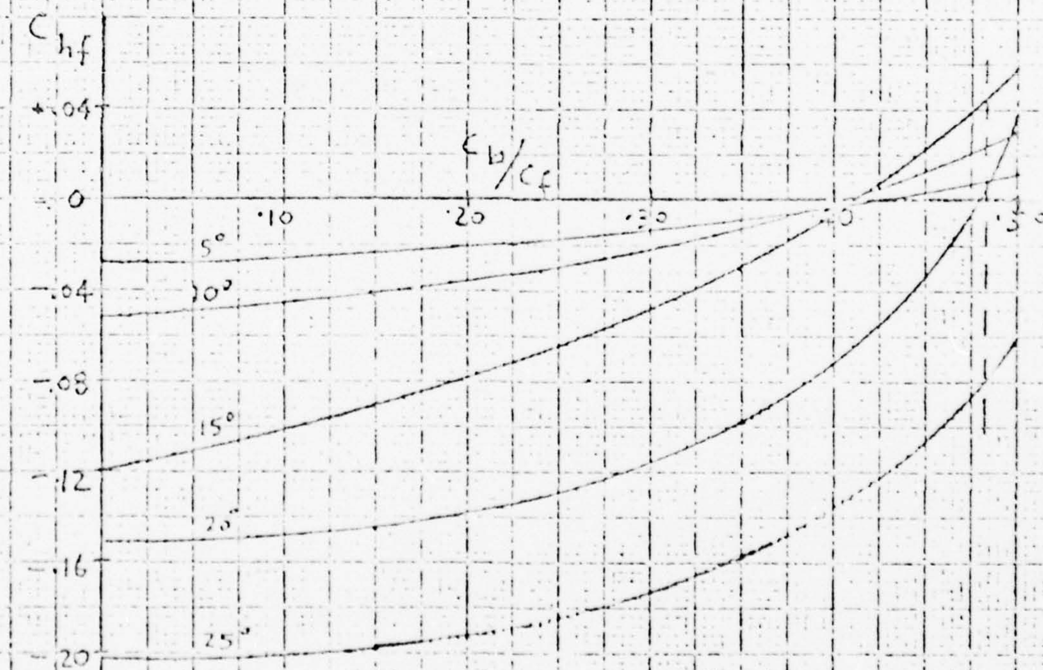


FIG 12. HINGE-MOMENT COEFFICIENT Vs C_b/C_f FOR VARIOUS PLANE ANGLE

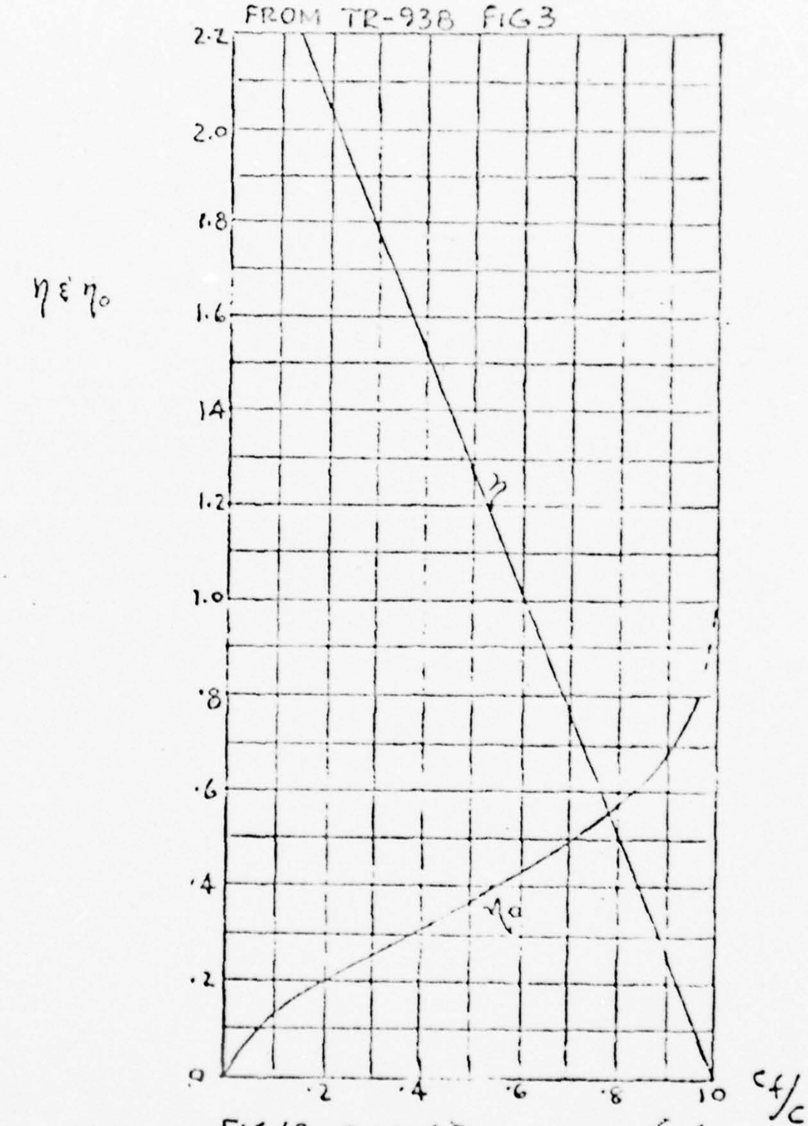


FIG 13 - FACTORS η & η_o VS c_f/c.

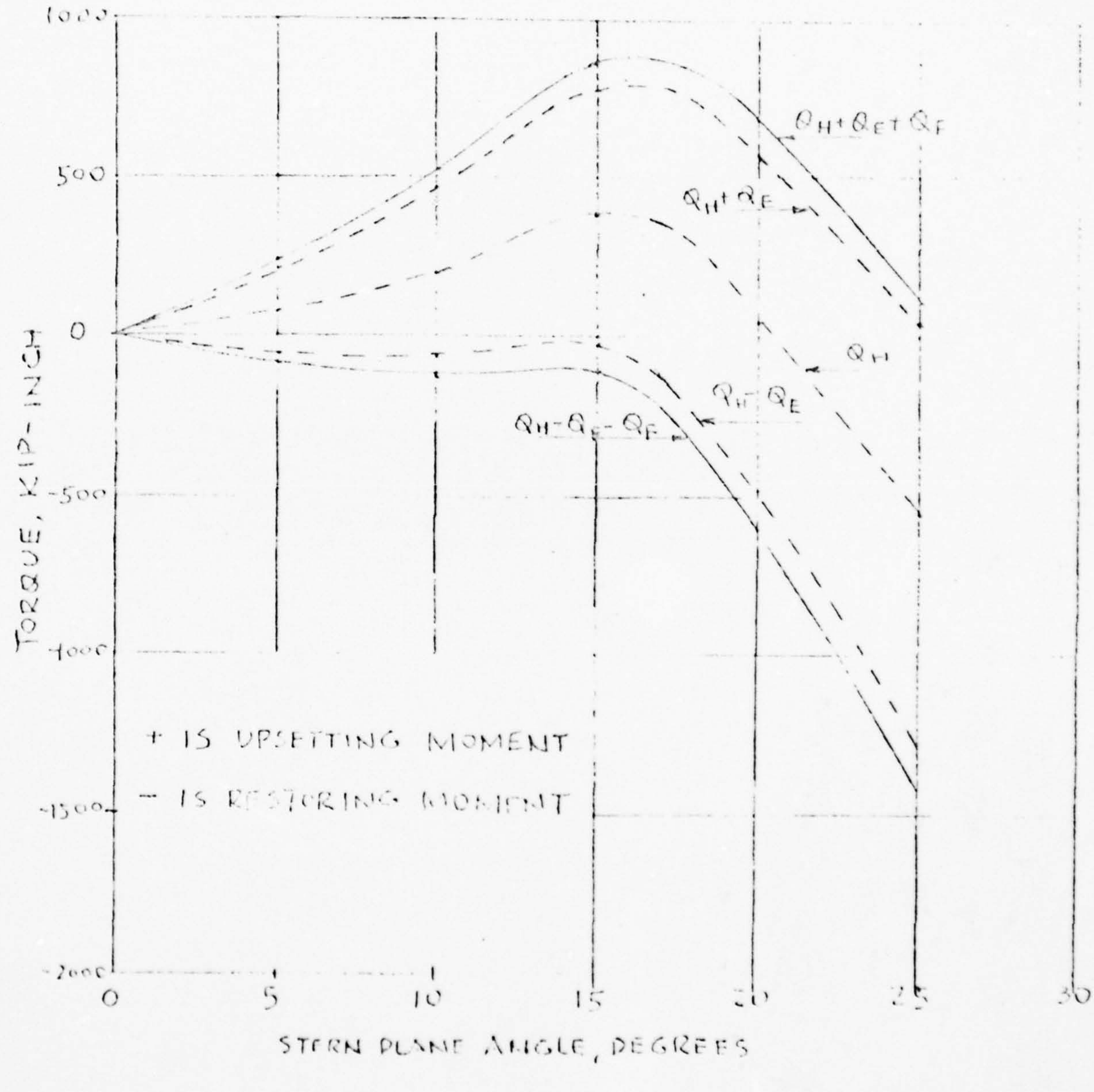


FIG. 14 - FINAL TORQUE CURVES

DEFINITION OF SYMBOLS USED IN STERN PLANE TORQE CALCULATION

A_f — AREA OF FLAP AFT OF STOCK

A_L — AREA OF STERN PLANE AND STABILIZER MINUS THE GAP AREA

A_{AR} — TOTAL STERN PLANE & STABILIZER AREA

A_P — AREA OF FLAP

A OR AR_e — EFFECTIVE ASPECT RATIO

b — TWICE THE SPAN OR 2S

C_b — CHORD OF PLANE FORWARD OF STOCK

C_f — CHORD OF PLANE AFT OF STOCK

C_m — MEAN CHORD $= \frac{1}{2}(C_T + C_R)$

C_T — TIP CHORD

C_R — ROOT CHORD

$C_{L\alpha}$ — LIFT SLOPE AT FINITE ASPECT RATIO

$C_{l\alpha}$ — LIFT SLOPE FOR ASPECT RATIO $= \infty$

C_L — LIFT COEFFICIENT

C_{hf} — HINGE-MOMENT COEFFICIENT

C_{Nf} — FLAP NORMAL FORCE COEFFICIENT

F_N — STERN PLANE & STABILIZER LIFT FORCE $\approx$ NORMAL FORCE

F_{Nf} — FLAP NORMAL FORCE

K_1 — RATIO OF ACTUAL ATTACK ANGLE TO ATTACK ANGLE GIVEN BY EXPERIMENTAL DATA

K_2 — RATIO OF ACTUAL HINGE-MOMENT COEFFICIENT TO THE HINGE-MOMENT COEFFICIENT GIVEN BY EXPERIMENTAL DATA

Q_H - HYDRODYNAMIC TORQUE

Q_F - FRICTIONAL TORQUE

Q_E - TORQUE ERROR ALLOWANCE IN TERMS OF FLAP CHORD

R_1 - GEOMETRIC ASPECT RATIO = $\frac{SPAN^2}{A_{AR}}$

S - SPAN OF PLANE & STABILIZER

S_F - SPAN OF FLAP (PORTION AFT OF STOCK)

y - DISTANCE ALONG SPAN STARTING FROM THE ROOT CHORD

α OR ϵ - ANGLE OF ATTACK (DOWNFLOW)

δ - FLAP ANGLE

ϵ_{ell} - ANGLE OF ATTACK FOR AN ELLIPTICAL LOAD DISTRIBUTION OVER THE SPAN

λ - TAPER RATIO

Ω - SWEEP ANGLE AT 1/4 CHORD

APPENDIX E

Abstracts from the Literature Survey

Title: Schoenherr, Karl E., "A Program for an Investigation of the Rudder Torque Problem," Marine Technology, July 1965.

Summary: In this paper the author outlines the areas of the rudder-torque problem by dividing it into a group of "basic factors," namely those determining the forces on a rudder in a free stream and "modifying factors," namely those changing the free-stream forces through the interference by the hull and the propeller. In conclusion the author presents a tentative program for future work he feels should be done in all areas.

Two rudder hydrodynamic torque calculation methods are discussed. The first is based on the laws of dynamical similitude applied to the whole system, so that rudder torque for a new ship is calculated from data obtained on a similar ship operating under similar conditions. The second method is based on dynamical laws applied to components of the system augmented by empirical or semiempirical correction factors, so that characteristic force and moment curves for a free stream rudder of the same type and shape are utilized and the interaction effects computed or estimated.

In addition some extracts from airfoil theory are included, and it is shown how the free stream rudder information for the second method above can be deduced from wind tunnel experiments or lifting line theory with empirical factors included (no profile shape or thickness included).

The "basic and modifying factors" which were not included above are then discussed in detail. These include shape and thickness of rudder profile; Reynolds Number and surface roughness; rudder angle; type of rudder; location of rudder; response of ship to rudder; Froude number; rate of laying rudder; immersion of top edge of rudder; proximity of top edge of rudder to shell of ship; position of shaft axis; rudder cavitation; rudder aeration; astern operation of ship; type of rudder drive and bearings.

No information is given for actual calculations.

Lastly, the author presents a "Tentative Program for Future Work." This program is as follows:

1. Review and improve theory of low-aspect-ratio airfoils with special reference to rudders.

2. Develop design formulas for C_L, C_D, and C_M for commonly used rudders.

3. Establish a rudder atlas which includes all known information on rudders that is of interest in Naval Architecture.

4. Conduct additional tests on flap rudders to obtain free-stream characteristics.

5. Design and test a systematic series of semi-balanced rudders (horn rudders.)

6. Explore the field of unconventional rudder types.

7. Conduct systematic tests to investigate the effects of hull proximity on rudder action.

8. Conduct systematic tests with various types of rudders to determine the effects of immersion.

9. Investigate the effect of end plates and fences.

10. Determine cavitation inception and the effects of well-developed cavitation on forces and moment for rudder forms suitable for high-speed vessels.

11. Design and construct one or more large rudder-test models for a systematic investigation of the hull-propeller-rudder interaction effects including the required instrumentation for simultaneous measurements of rudder lift, drag, moment and angle of model, speed, turning radius, drift angle, effective angle of attack and water speed at the rudder, propeller revolution, thrust and torque.

12. Conduct systematic tests on the special manned models according to carefully prepared plans and test schedules.

13. Conduct supplementary tests in one or more model basins on smaller scale models using the rotating arm and other established techniques to obtain the effects of independent variations of turning radius and drift angle and the effects of model scale.

14. Design a torsion meter for measuring rudder torque on full-scale ships.

15. Investigate hitherto untried methods for measuring the lateral force on a full-scale rudder.

16. Conduct full-scale tests on a few selected ships to check the results obtained in the special test model.

Comment: The various aspects of the rudder-torque problems are outlined and briefly discussed.

The first torque calculation method discussed corresponds to the Joessel method. The second corresponds to that embodied in DTMB Reports 933 and 1461 (Talpin), with either the graphs of DTMB 933 used for free stream characteristics, or the semi-empirical lifting line theory included in the same report.

No solutions to outstanding problems are given.

Titles: 1. Karamcheti, K., "Principles of Ideal-Fluid Aerodynamics," 1966

2. Milne-Thomson, L.M., "Theoretical Aerodynamics," 1966

3. Abbott, I. and Von Doenhoff, A., "Theory of Wing Sections," 1959

Note: The above three references are books and not all sections were reviewed.

Summary: Reference 1 describes the lifting line theory of Prandtl.

Reference 2 describes the lifting line and lifting surface theories.

Reference 3 gives some theory and experimental characteristics of wing sections of all types.

Comments: 1. Lifting line techniques may break down for aspect ratios less than four.

2. Lifting line techniques cannot use anything but near rectangular wing section.

3. Lifting surface theory can handle any aspect ratio or wing configuration.

4. Flaps can be added in the lifting surface methods.

5. Viscous effects should not be important (except for separation) except for possibly flapped wings.

Title: Abbott, I. H., Von Doenhoff, A. E., "Theory of Wing Sections," 1959

Chapter I - The Significance of Wing Section Characteristics

Summary: The main subject of this chapter was in presenting the semi-empirical lifting line technique for estimating the forces and moments on a wing. The steps of this method are as follows:

1. Assume a span-load distribution and solve for the corresponding downwash. (This will consist of evaluating the general lifting-line integral equation.)

2. The load distribution corresponding to this calculated downwash is then found using the lifting surface equations and the experimental wing section data.

3. This load distribution is compared with the assumed distribution.

4. If the assumed and calculated distributions do not agree, a second approximation is made of the load distribution.

5. The process is continued until the load and downwash distribution are compatible.

The applicability of section data to the prediction of the aerodynamic characteristics of wings is limited by the simplifying assumption made in the semi-empirical lifting line theory that each section acts independently of its neighboring sections except for the induced downwash. This required two dimensional flow, that is , no variation of section, chord, or lift along the span. This can have significant effects.

Also, it is assumed that the lift distribution is elliptical, which results in constant downwash along the wing. In addition, variation of downwash along the chord was neglected. This latter problem is avoided by lifting surface theory.

Experience has shown that usable results are obtained from lifting line theory discontinuities or rapid changes of section, chord, or twist are present, and if the wing has no pronounced sweep. These conditions are not satisfied near the wing tips or near the extremities of partial span flaps or deflected ailerons. The section data are not applicable to low aspect ratios.

Comments: The above theory is most probably applicable to unflapped foils of moderate taper and sweep of aspect ratio $\gtrsim 4$. Therefore, wing section data and its use in the lifting line theory is not useful for purpose of designing ship control surfaces. It should be noted that the lifting line and lifting surface rigorous calculation theories in use today do not make use of experimental section data but instead solve the corresponding boundary valve problem numerically.

Title: Abbott, I., Von Doenhoff, A., "Theory of Wing Section," 1959.

Chapter 7 - Experimental Characteristics of Wing Sections

Summary: I. Experimental Procedures

A. Tests with finite-aspect-ratio wings.

This method of testing is hampered by the difficulties of obtaining full-scale values of the Reynolds number and sufficiently low air-stream turbulence to duplicate flight conditions properly without excessive cost for equipment and models.

B. Two-Dimensional Testing

With this method wing sections can be tested in a two-dimensional flow at large Reynolds numbers in an air-stream of very low turbulence, approaching that of the atmosphere. The wing section data discussed here was from this type of test.

II. Standard Aerodynamic Characteristics - All results described below are for a large cross section of NACA wings.

A. Lift Characteristics

1. Angle of Zero Lift - Largely determined by the camber. The thickness ratio appears to have little effect on this.

2. Lift-Curve Slope - This varies primarily with the thickness. No systematic effect can be seen for changes in Reynold's number from $3 \times 10^6 - 9 \times 10^6$.

3. Maximum Lift – This varies with thickness and Reynolds number. Different NACA sections behave differently with Reynolds number NACA 00- four digit series (as used for ship control surfaces) show little change with Reynolds number (Reynolds numbers between 3×10^6 and 9×10^6 for .12c thickness are shown only.)

4. Effect of Surface Condition on Lift Characteristics. Surface roughness, especially near the leading edge, has a large effect on the lift of wing sections. The maximum lift coefficient decreases progressively with increasing roughness. The lift curve slope decreases with increased roughness, especially for thicker sections (over 18 per cent thick.)

B. Drag Characteristics

1. Minimum Drag of Smooth Wing Sections – This is shown to have little variation with Reynolds numbers between $.4 \times 10^6$ and 7×10^6 for NACA 00- sections.

2. Variation of Profile Drag With Lift Coefficient – Most of the variation of drag with lift for wings of finite span results from the induced drag coefficient, which varies approximately as the square of the lift coefficient for a given wing configuration.

Comments: The subject book is a famous writing and contains much experimental data.

The two-dimensional model testing technique outlined is not very useful for small aspect ratio control surfaces. The expense and turbulence factors seem to have limited the development of high Reynolds number foil data.

Reynolds number is shown to affect the maximum lift only. Although generally the maximum lift is increased for larger Reynolds numbers, in the case of NACA 00- series 4 airfoils, the effects seem neglegible (it is not known how much data backed this up.)

Since the lift curve slope is not altered by Reynolds number, and stall is not considered in ship control surface design, it appears that the effect of Reynolds number on lift can be negleted.

Because of the above, and since the greatest variation in drag is due to the induced drag (potential and not viscous), it appears that the drag and lift characteristics of ship control surfaces can be predicted without considering viscous effects. However, nothing has been mentioned with respect to the variation of drag v.s. angle of attack for various Reynolds number. This is important for center of pressure calculations.

Title: Lan, Chuan-Tau, "An Improved Nonlinear Lifting-Line Theory"

AIAA Journal, May 1973

Summary: This method presents an improvement over Prandtl's lifting line theory for non-linear section lift curves.

Comment: Since conventional ship control surfaces do not have non-linear section lift curves, this method is not of importance here.

Title: Ting, L.; Lui, C.H., "Interference of Wing and Multipropellers," AIAA Journal Vol. 10, No. 7, July 1972

Summary: A method is presented for determining the properties of wings in conjunction with propeller streams. The propeller streams need not be uniform.

The method makes use of Prandtl's lifting line theory for the overall calculation. The assumption is made that the radius of the propeller and the chord are of the same order and both are much smaller than the span.

Comments: This presentation shows how a non-uniform inflow can be considered while computing the properties of a wing.

The basic procedure involves the lifting line theory, which shows some breakdown at small aspect ratios (<4).

Title: Langan, T.J., Wang, H.T., "Evaluation of Lifting-Surface Programs for Computing the Pressure Distribution On Planar Foils In Steady Motion," NSRDC Report 4021, May, 1973.

Summary: The pressure differences, forces, and moments on the same two wings (one tapered and the other swept with no taper; both with aspect ratio of 5) in steady subsonic flow were computed by 15 different programs (mostly from the aeronautical field) and compared with each other and experimental data.

Some of the programs showed differences from the experimental results which were less than experimental accuracy. It should be noted that although some of the programs could account for thickness, this was not included in that all programs solved for the potential flow around an infinitesimally thin wing. The authors themselves stated; "Our limited results support the use of lifting-surface programs for the design of wings, at least for computing the overall wing coefficients."

Execution times on different computers were also noted.

Comments: The computation that was done by each program in the report was that of determining the free stream characteristics of the particular wing configuration. This is what is accomplished by DTMB Report 933 for the present procedure for spade type surfaces.

Because the details of each particular program were not given, it can not be determined what full capabilities can be derived from the methods discussed. The programs which showed good results will be further investigated to determine to what detail a control surface can be described, with the hope that both spade and flapped type control surfaces can be modeled for any speed. This could ultimately give accurate free stream characteristics for any control surface.

The unsteady flow problem was not discussed.

The computer execution times noted indicate the theoretical procedures can be within economical considerations.

Title: Wang, Henry T., "Comprehensive Evaluation of Six Thin Wing Lifting Surface Computor Programs," NSRDC Report (to be published).

Summary: The report describes a comprehensive evaluation of six thin wing (although some have thick wing capabilities) lifting surface computor programs for steady subsonic flow. Sixty two planform cases, eighteen camber cases, and two flap cases were considered. The aspect ratios were from 1-12, sweep of the quarter chord line from 0 to 45 degrees, and taper ratio from 0.0 to 1.0.

The programs compared and a brief description of their additional attributes is given below:

1. Margason-Lamar Program (NASA Langley)

Experience with this program shows that the overall aerodynamic coefficients have converged to at least two and possibly three figures.

This program can also deal with the case of a wing with dihedral and the case of a wing in the presence of another wing or tail.

2. Lopez-Shen Program (McDonnell Douglas)

In addition to the thin wing problem considered, this program can handle wings with a jet sheet of varying strength issuing along the trailing edge.

3. Tulinius Program (North American Rockwell)

This program can account for wing thickness as well as the presence of a fuselage.

4. Bandler Program (Engineering Research Associates)

This program was written to analyze hydrofoils. Thus, it allows for free surface and Froude number effects. Thickness effects are accounted for in a linearized sense, in that at infinite depth, thickness does not affect lift but serves only to determine the pressure distribution over the foil. This is needed for cavitation. More recently, the program has been expanded to analyze a hydrofoil with pod.

5. Lamar Program (NASA Langley)

6. Wagner Program

The first five programs were used because they gave good results in NSRDC Report 4021. The last program above was added to the previous list.

Except for the Bandler program and to a lesser degree the Lopez-Shen program, the programs showed generally good agreement in the planform cases with low sweeps. The Tulinius results are in closer agreement with experimental results for wings with quarter-chord sweep up to about 40 degrees, while the reverse is true at larger sweeps. The

lift coefficient is usually predicted to within four percent. This difference is not substantially greater than the difference due to measuring techniques, changes in Reynolds number, or changes in airfoil section.

The agreement between experimental results and computer prediction is quite poor for the two flap cases considered in the report. More flap cases should be considered in order to more clearly ascertain the accuracy of the program for these cases. (The flaps were on triangular wings.)

Considering both accuracy and computer time requirements, the author recommends the Tulinius Program. The other three programs that showed good results rate as a second choice principally due to somewhat longer computer time.

Comments: The results of the paper demonstrate that it is possible for present lifting surface theory programs to compute the hydrodynamic (or aerodynamic) characteristics of certain control surfaces.

It is obvious that more comparison and possibly some additional work on the theory is needed before general use is made of them for ship related problems.

Comments: The computation that was done by each program in the report was that of determining the free stream characteristics of the particular wing configuration. This is what is accomplished by DTMB Report 933 for the present procedure for spade type surfaces.

Because the details of each particular program were not given, it can not be determined what full capabilities can be derived from the methods discussed. The programs which showed good results will be further investigated to determine to what detail a control surface can be described, with the hope that both spade and flapped type control surfaces can be modeled for any speed. This could ultimately give accurate free stream characteristics for any control surface.

The unsteady flow problem was not discussed.

The computer execution times noted indicate the theoretical procedures can be within economical considerations.

Title: Tulinius, J., "Theoretical Predictions of Wing - Fuselage Aerodynamic Characteristics at Subsonic Speeds," North American Rockwell, Serial No. NA-69-789.

Summary: A method is presented to predict the aerodynamic characteristics of a wing-fuselage combination at subsonic speed.

Both the wing and the fuselage can be of arbitrary shape, provided the surface gradients are smooth. The wing geometry can include full or partial span flaps on both the leading and trailing edges. All interference effects between the fuselage, wing, and flap geometry are included.

The program considers only potential flow (i.e. no boundary layer or separated flow).

The analysis is such that it can be extended to account for wing thickness, horizontal and vertical tails, nacelles, and pylons. It could also easily be extended to account for antisymmetric wing and fuselage loadings due to the roll.

Comments: Apparently the program can accept a body with control surfaces with antisymmetric loading. Details of the program are not known.

This program gave good results when compared to others by Wang.

Title: Bradley, R.G., Miller, B.D., "Application of Finite-Element Theory to Airplane Configurations," J. Aircraft, Vol. 8, no. 6 June 1971.

Summary: The authors compare the calculated pressures and some lift and moment output from the Woodward and Hague "Finite Element Computer Program for the Aerodynamic Analysis and Design of Wing-Body-Tail Combination at Subsonic and Supersonic Speeds" (General Dynamics Corp.) with experimental results. The computed and experimental quantities are for two supersonic warplanes at both subsonic and supersonic speeds. The results show good agreement.

The authors note that the calculations for one of the airplanes required one hour on an IBM 360 model 65 computer. The authors also point out that at the present time the use of the finite-element approach is not a push-the-button task but instead involves insight in the theory limitation in order to accurately apply the numerical method to complex configurations.

Comment: The paper considers the finite-element approach as opposed to the collication approach to numerical lifting surface theories.

The comparisons with experimental results indicate that the finite element approach can model complex wing-body-tail combinations with good accuracy.

Title: Loftin, L. K. Jr., Dursnall, W. J., "The Effects of Variations in Reynolds Number Between 3.0×10^6 and 25.0×10^6 Upon the Aerodynamic Characteristics of a Number of NACA 6 - Series Airfoil Sections," NACA Report 964.

Summary: All tests were done in a two dimensional wind tunnel.

An investigation was carried out to determine the aerodynamic characteristics of a number of systematically varied NACA 6-series cambered airfoils at Reynolds numbers of 15.0×10^6 - 25.0×10^6, and were combined with the results from another source for Reynolds numbers between 3.0×10^6 and 9.0×10^6. The thickness of the airfoils was varied between 6 and 18 per cent of chord.

The most important conclusions were that minimum drag, section lift curve slope, and the angle of zero lift showed very little change with increasing Reynolds number. However, maximum lift and the variations of drag with lift did show variation with Reynolds number.

Throughout the range of Reynolds numbers the values of the lift curve slope for smooth sections was very close to that predicted by thin airfoil theory, even for thick sections.

Maximum lift results showed different variation with Reynolds number for different thicknesses.

The drag results indicated that for Reynolds numbers between 3.0×10^6 and 9.0×10^6 the drag decreased with increasing Reynolds number, for the same lift coefficient. For Reynolds number above 9×10^6, further increases in the Reynolds number did not have appreciable effects upon the drag.

The authors feel that any comparison of airfoil maximum lift characteristics can be made only if the data for the group of airfoils under consideration are available at the same Reynolds number. The choice of an optimum airfoil for maximum lift for a given application, therefore, must be determined from data corresponding to the operating Reynolds number of the application.

Comments: Since the slope of the lift curve does not vary, the maximum lift changes with Reynolds number do not affect ship control surface design.

Since the drag decreases as Reynolds number is increased, for lower Reynolds nubers as indicated above, it is possible that in the current use of DTMB 933 to extrapolate to much higher Reynolds numbers, there is error in the estimation of drag.

Since the lift is independent of Reynolds number for ship control surfaces, and at high Reynolds number the drag does not vary appre-

ciably (which seems to indicate viscous drag is small), it appears that the potential solution of the problem is only of consequence (which is the part of the solution considered by lifting line and lifting surface programs.)

Title: Thieme, H., "Design of Ship Rudders," DTMB Translation 321.

Summary: The main purpose of this paper is to discuss the stream-lining of guiding head (bow) and balanced rudders. New profiles in particular are examined. One test series examines the influence of the thickness ratio, aspect ratio and Reynolds number on rudder forces and moments. The author also discusses conventional methods for determining required area and rudder positioning.

Comments: This paper is of limited use in the revision of the current design procedure; however, it does present some experimental results concerning matters related to the design procedure. Results for square plates for various Reynolds numbers and thickness to length ratios are given. These could be correlated with Joessel's data.

The effect that rudder shape has on the force coefficient for various aspect ratios is given. The indication is that the force coefficient varies greatly at low aspect ratio and that sectional shape has a large influence on the force coefficient.

Also, the report indicates a large difference in transverse force coefficient (lift coefficient) with respect to Reynolds number.

Title: Kerwin Justin E.; Mandel Philip; Lewis S. Dean;
"An Experimental Study of a Series of Flapped Rudders";
Journal of Ship Research, Dec. 1972.

Summary: This paper describes a series of wind tunnel tests on twelve flapped rudders to determine the lift, drag, rudder moment and flap moment coefficients. Variations are made in the amount of flap area and flap balance. A comparison is made with all moveable rudders, fixed skegs with flaps and moveable skegs with a flap.

The paper concludes that:

(1) Root gap, flap gap and type of wall mounting have a significant effect on experimental rudder hydrodynamic characteristics.

(2) Large flaps with fixed skegs can yield maximum lift coefficients nearly as large as those of spade rudders but at the expense of increased drag and torque.

(3) The size of the flap between 20 percent and 50 percent of the total rudder area has little effect on maximum lift.

(4) Maximum flap hinge moments are much less than the maximum rudder moment acting on the spade rudder.

Comments: This paper is interesting for its contribution to the horn rudder and stern flap with stabilizer design procedures. Unfortunately it is impractical to make a direct comparison between the data in this report and the present design procedures since the Reynolds number is in a different range and the height to chord ratios for the rudders used in this report are much higher than those used in Report #915 for the horn rudder.

Title: Windsor, R. I.; "Effects of Streamwise Gaps, Hull Flow and Propeller Slipstream Upon the Aerodynamic Characteristics of A Family of Low-Aspect-Ratio, All Moveable Control Surfaces;" University of Maryland Report No. 485; March 1968.

Summary: The control surfaces used in this report had the NACA 0015 airfoil section, square tip and taper ratio of 0.45. Tests are run for effective aspect ratios of 1, 2 and 3 and quarter chord angles of 0, 11 and 22.5 degrees for faired gaps up to 40% of the planform mean chord. Three different test series were run:

1. Free stream gap effects.

2. Gap with simulated hull flow.

3. Combined hull flow and slipstream effects for minimum gap configurations.

The conclusions reached for free stream gap effects are as follows:

1. Because theoretical considerations disregard the effect of visiosity, the gap effects upon lift and drag was considerably less than theory would predict. The theory they refer to was taken from work performed in the early 1950's.

2. Aspect ratio appears to have no bearing on the gap effects.

3. This is a change in gap effect with sweep angle - the smaller the angle the greater the change in the gap effect.

4. Maximum gap effects occurs with small gaps and these effects dimenishing with increasing gap size.

5. Although there is not much experimental evidence to support this, the experimenter feels the boundary layer thickness may change the region of maximum gap effects.

The conclusions reached for the gap effects with the simulated hull are as follows:

1. As is expected the lift coefficient increases as gap size increases due to the effect of the velocity gradient for the simulated hull flow.

2. The gaps effect on $CP_{\bar{c}}$, drag and spanwise center of pressure are very close to those effects in the freestream condition.

In the final test series a propeller was added in the slipstream to the simulated hull flow. The following conclusions are

reached:

1. The chordwise center of pressure moves aft with an increase in quarter chord sweep. The maximum shift is 2% of chord for a sweep angle of 22.5 degrees. This shift results from the velocity gradient.

2. There is a slight inboard shift of the spanwise center of pressure for the aspect ratio 2 surfaces and a slight outboard shift for the aspect ratio 3 surfaces.

3. Increased slipstream velocity overcomes the reduced velocity of the hull.

4. Slipstream twist overcomes the effect of hull flow angularity.

5. The stall angle is increased in the slipstream by 3 - 6 degrees for every trial.

6. Chordwise and granwise center of pressure locations vary considerably for different aspect ratios and with angles of attack. The cause for these shifts is unknown.

Comments: These experiments are too limited in scope to provide a tool for the prediction of rudder torque. This is particularly true for the portion of the experiment which involves full effects and slipstream.

Title: Windsor, R. I., "Effects of an Underwater Hull on the Hydrodynamic Characteristics of a Series of Control Surfaces," University of Maryland Wind Tunnel Report No. 660.

Summary: This report describes a series of experiments which determine the effect of a submarine hull on its control surfaces. The geometric characteristics of the control surface model are given below.

TABLE I

Geometric Characteristics of Control Surface Models

ASPECT RATIO AR_G	TAPER RATIO TR	MEAN CHORD $\bar{c}$ (FT.)	TIP CHORD c_t (FT.)	ROOT CHORD c_r (FT.)	PLANFORM AREA S (SQ. FT.)
1	.20	1.391	.464	2.318	1.934
1	.31	1.391	.658	2.123	1.934
1	.90	1.391	1.318	1.464	1.934
1.58	.20	.880	.293	1.467	1.224
1.58	.31	.880	.417	1.344	1.224
1.58	.90	.880	.834	.927	1.224
2	.20	.695	.232	1.159	.967
2	.31	.695	.329	1.062	.967
2	.90	.695	.659	.732	.967

The submarine hull tested was the SSN637. Two series of tests were run with the control surfaces described above, the free-stream test and tests for the control surface at various locations on the hull.

The data plots developed show force coefficients, moment coefficients, and spanwise and chordwise center of pressure versus angle of attack.

The following conclusions were reached for the free-stream tests.

1. Lift curve slope increases with increasing aspect ratio.

2. Chordwise center of pressure (CP_c) moves forward with increasing aspect ratio.

3. CP_c travel with changes in attack angle and decreases as aspect ratio increases.

4. Maximum lift coefficient increases with increasing taper ratio except for aspect ratio 1 surfaces where this coefficient is essentially constant.

5. CP_c moves aft slightly with increasing taper ratio.

6. *Spanwise center of pressure moves outboard with increasing taper ratio.*

7. For aspect ratio = 1 surfaces, lift curve slop:increases with increasing taper ratio.

Some comparisons were made between a NACA 0020 and NACA 0015 airfoil profile.

1. The maximum lift coefficient is lower for 0020 surfaces.

2. Lift curve slopes are lower for 0020 surfaces.

3. Chordwise center of pressure for the 0020 surfaces is consistantly 2-4% forward of the corresponding 0015 configuration.

The following conclusions were reached when tests were run for hull effects.

1. Presence of the hull causes chordwise center of pressure to move forward for the trailing edge down condition.

2. Little or no change in $CP_{\bar{c}}$ for trailing edge up.

3. Maximum lift coefficient decreases in the presence of the hull.

4. $CP_{\bar{c}}$ moves further forward in the high fairwater plane position for trailing edge down condition.

5. Large shift in drag curves for aspect ratio AR = 1 surfaces.

The shifts in drag coefficients for AR = 1 are probably due to streamwise gap effects. The gaps for the larger aspect ratio foils was much smaller.

There is little or no change in the coefficient measured for changes in position of the control surface on the hull.

Comments: In general it could be said that submarine hull effects and fairwater plane position have only small effects on the lift and drag characteristics. The data should be studied to see if the present center of pressure error allowance for fairwater and stern phones is adequate, although the data should be used with caution since some of the $CP_{\bar{c}}$ values are considered questionable.

Title: Taggart, R., Levine, G.H., Stevenson, M., "Design Prediction of Steering System Torques," NAVSEC Report under Contract N00024-68-C-5454, September 1969.

Summary: In this report the authors attempt to reproduce measured steering gear torque of the DE 1040 class of Destroyer Escort for which a wealth of full scale maneuvering data and numerous steering system measurements are available. To reach this end they develop a steering system torque prediction procedure which includes ship motion, propeller effects, mechanical and hydraulic system effects, and rudder hydrodynamic characteristics. They feel that the full scale data measured was duplicated to acceptable accuracy by their procedure.

Finally the authors recommend before their procedure is used for future designs, it is essential that it be evaluated on a number of other classes of ships. This evaluation, they say, is needed both to check the validity of several of their assumptions and to perhaps reduce the complexity of the calculation procedure. Specifically they recommend additional studies be carried out to learn more about the performance of rudder-shaped hydrofoils in non-uniform flow.

Title: Windsor, Richard A., "Wind Tunnel Test of An Equivalent Flapped Control Surface of the SS (N) 593 Stabilizer and Stern Plane," University of Maryland Wind Tunnel Report No. 302

Summary: Wind tunnel tests were conducted on an equivalent flapped control surface of the SS (N) 593 stabilizer and stern plane. The tunnel tests were conducted to obtain total lift, drag, normal force and pitching moment coefficient, flap hinge moment coefficient, and spanwise and chordwise center of pressure for flap angles up to 40°. Tests were run where the coefficients above were measured for the complete control surface and then were measured for the flapped portion alone.

Comments: The data in this report is of limited use in our study since it treats only one stern plane of a given flap area, aspect ratio, Reynolds number, and flap balance. Since the scope of the tests is so narrow, the data could not be used as a design tool.

One possible use of this data would be to use the physical characteristics of the stern plane in a calculation procedure to see if the results predicted by calculation agree with the test results of this report.

Comments: The authors present a system design approach to the problem of ship maneuvering. Unfortunately many aspects of this problem are of such a nature that they cannot be presently described accurately by theory or formula (i.e. ship motion, rudder hydrodynamic torque, propeller wake, propeller slipstream, etc.), so that considerable built up error can be encountered in such a system approach. Also, many of the theories and formulas presented by the authors appear to indicate a limited search of available works in the respective areas, and some assumptions are made without sufficient justification.

Since the detail calculation deals with only one class of ships, no general conclusions can be made.

The authors do not present any criteria for rudder size, location, shape, angle of attack, type, or inflow velocity. Instead, they feel an initial design should be guessed at and then verified by the procedure, with all necessary quantities determined by the systemized procedure. DTMB Report 933 is still recommended for lift, drag, and center of pressure of rudders.

It is concluded that although this report indicates most of the considerations involved in the ship maneuvering problem and indicates a possible design procedure, because of the lack of theoretical and experimental backup that is presently available, the procedure cannot be used for present design purposes.

The research the authors recommend for rudders in non-uniform flow is good. Evaluation of their method with other classes of ships is not essential, since the inaccuracies in the theoretical procedures they make use of are still too great to consider the rudder torque problem in a complete system approach technique.

APPENDIX F

Original NAVSEC Technical Practices Manual

APPENDIX F

RUDDERS AND SUBMARINE CONTROL SURFACES 9220-1 (Code 442)

A. Rudder Design

Practice:

Section 1. – General

1.1 The aim of rudder design is to provide tight turning, good ability to initiate and check swings rapidly, and good course-keeping ability. Quantitative measures of these are usually investigated by tactical diameter, zig-zags (Kempf or Z-maneuver) and spiral maneuver (Dieudonne) model tests. For replenishment ships, the approach and alongside positions are sometimes investigated in model form. Of course structural reliability, minimum propulsive losses and overall cost must be included to obtain complete balanced design.

1.2 The best sources of general design practice are the 1953 Trans. SNAME article "Some Hydrodynamic Aspects of Appendage Design" by P. Mandel and "Hydrodynamics of Ship Design" by Capt. H. E. Saunders. For merchant ship types, typical practice is best shown in J. P. Comstock's article in "Design and Construction of Steel Merchant Ships" by Arnott. Two publications, the SNAME revised edition of Principles of Naval Architecture and a SNAME Panel H-10 Notes on Ship Controllability are expected to be issued in the near future. The manuscript copies indicate they will be very useful.

1.3 For a specific ship type, usual design practice is to first study the design history of earlier ships of the type and to check with the Type Desk for maintenance problems.

Criteria:

Section 2. – Rudder Planform and Location

2.1 Current practice in selecting rudder planform and location generally follow the theory in the 1953 Trans. SNAME article by P. Mandel. The tabulation of characteristics on page 432 is for specific ships of the U. S. and British Navy and the identification code is available in Code 421 or 442. Model tests are usually run to verify the prediction. Ship characteristics generally indicate desired maneuvering performance. Model tests tests for tactical diameter are usually reliable to within plus or minus 5 percent. In rare instances there are larger discrepancies, such as on DLG 16 where full scale tactical diameter was 16 percent greater than model data (DTBM Reports C-975 and C-1700). It should be noted that full-scale tactical data are sometimes erratic, so that correlation with model data reflects more than just scale factors. A 10 percent margin on tactical diameter by model test predictions is considered a minimum, with a 15 percent margin desirable if readily attainable.

2.2 Additional items to consider are:

(a) Rudders are generally moved out of a position directly in line with propeller shafting in order to avoid the propeller tail cone vortex. This is done even for single screw ships (e. g. DE 1052) with high power. AGDE 1 is an exception to this practice, since it is expected that the pumpjet will eliminate the tail cone vortex. Auxiliaries with low power are usually built to merchant standards, with the rudder in line with the tail cone.

(b) Unshipping of propellers and shafting should be investigated and adequate clearance provided without having to unship a rudder. In some cases unshipping the tail shaft may require turning the rudder and removing portable rudder plates. This is avoided wherever possible.

(c) The rudder should be well submerged even with the ship lightly loaded aft and heeling in a turn.

(d) The rudder-rudderstock combination of tapers and location are made such as to permit unshipping the rudder without special high blocking. Where the rudder cannot be dropped enough directly downward, provision should be made for first lifting the stock within the ship. Tilting the rudder on the stock taper is possible, but is avoided except as a last resort.

Section 3. – Calculation of Rudder Forces, Moments, and Balance

3.1 This section represents recent practice, as revised, to take advantage of AOE 1 and AS 33 lessons. From analysis of full-scale AOE 1 data, recorded by Puget Sound Naval Shipyard, the effective attack angle should be taken as 0.77 times rudder angle, rather than 5/7 = 0.71 formerly used. From Puget Sound's AS 33 data some allowance should be made for torque, say 20 percent of maximum, at zero rudder for a rudder in a propeller race. DTMB Report 060-H-01 of March 1965 reports model tests of AS 33 forces and torque. Forces correlate well with design theory; torques do not correlate with either design theory or full scale data. The error allowance in estimating chordwise center of pressure should be increased generally (as indicated in paragraph 3.5 which has new values) for so important a system. Regarding specifications, the assumed efficiency from steering gear hydraulic torque to rudder stock will no longer be stated. In general, performance requirements will be specified, with Bureau-predicted forces and torques for guidance only. This concentrates responsibility in case there are defects in rudderstock bearings, steering gear, or anything else not foreseeable. Actual problems have been as varied as poor pump bearings on one ship of DLG 16 Class, and leaky rams on one ship of CVA 59 Class. Where weight is of more than usual importance, the design may include more specific requirements than merely performance. This essentially involves taking some risk where weight saving makes that course desirable. The computation is by aerodynamic methods, with some additional features needed for ship applications. The most important publications for this work are DTMB Rept. 933 "Free-Stream Characteristics of a Family of Low-Aspect-Ratio, All-Movable Control Surfaces for Application to Ship Design" (Revised Edition), and University of Maryland Report 62-1 "Survey of Low-Aspect-Ratio Characteristics Useful in the Design of Control Surfaces" dated Nov. 1962. Forces and centers of pressures are computed as indicated below, and additional allowances are made for converting hydrodynamic torque into steering gear torque.

3.2 The computations for forces and centers of pressures involve finding data for the right range of Reynolds Number and correcting for:

(a) Effective aspect ratio (A. R. Geometric $= \dfrac{\text{Span}}{\text{Chord}} = \dfrac{(\text{Span})^2}{\text{Area}}$; A. R. effective varies from 1.0 to 2.0 times geometric, depending on root gap and hull shape over).

(b) Taper ratio ($\lambda = \dfrac{\text{Tip chord}}{\text{Root chord}}$)

(c) Sweepback angle (Ω = angle that the quarter chord line makes relative to the flow).

3.3 The attack angle (α) for rudders is usually taken as 5/7 the rudder angle. This is an arbitrary drift angle allowance, based on the time to get the rudder over (about 10 seconds) and the expectation that the ship will have started swinging by then. This arbitrary value transforms a 35 degree rudder angle into a 27 degree attack angle, below stall in most wind-tunnel data.

3.4 The speed used is that in way of the rudder during a full-power straight-running period. The ship should be assumed in a light-displacement clean-bottom condition such as can occur on builders trials. Any reduction of speed in a turn is a hidden factor of safety, and is not calculated. For rudders in a propeller race, flow speed is taken as the product of ship speed times 1 plus slip, and is considered as acting over the rudder area shaded by the slipstream. For rudders or portions of rudders not in a race, ship speed is used over the entire span. For a more realistic velocity survey aft of a propeller, see page 4 of DTMB Rept. 1188 "An Investigation of a Flow-Excited Vibration of the USS FORREST SHERMAN (DD931)".

3.5 With these simplified methods of estimating flow speed and angle of attack, the ordinary coefficients (lift, drag, normal force, chordwise and spanwise center of pressure) are obtained by cross-fairing as indicated by Section 3.2. A systematic plot of data by Electric Boat Division (available in Code 442) is very useful for this. The rudder torque so obtained is called Q_H the hydrodynamic torque. Airplane nomenclature is followed, with negative torque indicating a trailing tendency (center of pressure aft of stock). An allowance for uncertainty in center of pressure is made generally ±2 to 4 percent of the mean chord. This allowance, multiplied by the normal force, results in a ± Q_E, or torque error allowance. This is added algebraically to the Q_H curve, and converts it into a band in lieu of a line. (Note that no error allowances are made for force or spanwise center of pressure). This band is then further modified to get steering gear torque by allowing for the intervening friction Q_F. This is done by computing reactions at

all bearings, multiplying by a friction coefficient (see section on Bearings) to get the frictional force, and multiplying that by the radius of stock or sleeve to get frictional torque. The best example of this systematic procedure and the sources of aerodynamic data are shown in the Code 442 rudder file for SSB(N) 608 Class.

3.6 Rudder balance may be theoretically selected in one of these three general ways:

(a) For minimum size of steering gear. This requires balancing the negative and positive torque envelopes of $Q_H : Q_E : Q_F$. (Some allowance can be made for varying mechanical advantage of the steering gear at different rudder angles). This is done where weight is very important.

(b) For a rudder which will trail at very near zero if the steering gear exercises no restraint. This fail-safe feature requires considerable steering gear capacity, hence is not usually done.

(c) For something between (a) and (b) above. This is the usual practice, and balance should be selected so that Q_H goes through zero somewhere between 50 percent and 80 percent of maximum rudder angle. The precise value depends on the shape of the torque curves, and is a matter of designer's judgement.

Section 4. – Rudder and Rudderstock Stress Analysis

4.1 Because of the importance of rudders in controlling a ship, a stress analysis is usually made during design, and the shipbuilder is usually required to make one based on actual scantlings. Stresses are limited so as to provide a minimum factor of safety of 2.0 on yield with loads computed as indicated in Section 3.2. Where loads are estimated by less reliable means (e.g. Joessel's formula) the minimum factor of safety is taken as 2.5 on yield.

4.2 For semi-balanced rudders with horn, the best practice is available in Code 442 files for the BB61 stress analysis by New York Naval Shipyard. For gudgeon strength (designed as elastic arch) a method devised by L. W. Ferris is used and available in the Code 442 files.

4.3 For spade rudders the best practice is shown in Code 442 files for the Gibbs and Cox stress analysis of DD931 Class and DL2 Class rudders.

4.4 A computation for rudder hub strength is shown in the Code 442 files for CVA(N)65. DTMB Report *Experimental Stress Analysis of a Socketed Connection in Bending* by L. A. Becker has some useful test data.

4.5 There are also problems with non-hydrodynamic loads on rudders. AKA, AGB, and LST types have twisted rudderstocks while operating in ice, and landing craft have twisted stocks after beaching and broaching with rudders in the sand. In some cases replaceable shear pins have been installed to protect the steering gear from such damage.

Section 5. – Rudderstock Material

5.1 For rudders welded integrally to the stock, we specify the low carbon forged steel MIL-S-20140. (See LSD28 and DE1006 plans for details.) This steel has 30,000 p.s.i. yield and 60,000 p.s.i. ultimate strength.

5.2 Beginning approximately April 1965, steel forgings for rudderstock socketed connections have generally be ordered to Mil. Spec. MIL-S-23284. This will permit easier weld repair capability than Mil. Spec. MIL-S-890, which had been used for many years.

5.3 The use of higher strength steels tends to save weight and permit thinner rudder sections, both of which are desirable. There are, however, the following drawbacks: (a) the deflection of the stock tends to be greater, involving a potential problem with seals and, (b) the natural frequency tends to be lower, which probable involves a little more potential vibration.

5.4 Where rudderstocks are required to have little or no magnetic permeability, aluminum bronze has worked well on AMS60 and MSO421 Class. World War II minesweepers had rudderstocks of Tobin bronze (which is really a brass). These bent and twisted in service, hence the later designs used the high-grade and costly aluminum bronze.

5.5 In selecting rudderstocks, corrosion resistance is desirable (since protective coatings are not yet reliable). Ordinary fatigue is not considered to be a problem since there are generally only a few cycles of high stress a year (ship at full power with full rudder angle). Notch toughness is highly desirable, since corrosion pitting is probable over the course of years.

Section 6. – Rudder Plating and Framing

6.1 Present practice is to adjust plating and framing to get panel sizes of span equal to about 40 thicknesses of plating. Earlier designs with greater spans (e.g. DD445 Class, DD692 Class, CVA41 Class) suffered loss of rudder plating from panting, fatigue, corrosion, and erosion.

6.2 For rudders not in a propeller race the plating is usually M.S. (e.g. DL1). For rudders in a propeller race, S.T.S. or HY 80 are generally specified (e.g. DL2 Class) because of superior strength and slightly improved corrosion resistance compared with H.T.S. and M.S.

6.3 At the trailing edge of the rudder, a rabbeted casting or forging, with equal galvanic

property as the side plating, provides the strongest construction (e.g. DL2). Where economy is important, the side plates can be welded to one another (e.g. DE1006).

6.4 Valuable information on this subject is available in TMB Rept. R-354 "Notes on Casualties to the Twin Rudder of United States Destroyers" by Captain H. E. Saunders.

Section 7. - Bearings

7.1 Bearings are to be designed to take the rudderstock radial and thrust loads and the rudderstock flexural deflection. These are computed using:

(a) Hydrodynamic loads on rudder

(b) Weight of rudder plus stock

(c) For design which includes shock resistance as a requirement, (a factor from General Specifications 9400-1) times the weight produces radial and thrust loads which are not combined with (a) and (b) above.

7.2 Bearings are of two basic types:

(1) Rolling friction or anti-friction (such as roller or ball bearings) and

(2) Sliding friction or sleeve (such as floating collars for thrust, bronze sleeve and phenolic bearing type for radial). Recent examples of these types are shown, respectively, on plans DD927-S2202-760457 and DD931-S2200-1426955.

7.3 We have been using friction coefficients of 0.01 for *anti-friction types*, and from 0.15 to 0.20 for sleeve types. These values are based on commercial practice and some brief tests at Portsmouth Naval Shipyard. In connection with torque estimates, there may be some margin in the 0.2 coefficient for sleeve bearings. There is no significant margin in the 0.1 coefficient for anti-friction bearings.

7.4 Sleeve bearings have low initial cost, are relatively easy to maintain, and in most cases would be relatively easy to repair in emergencies. We usually specify staves of laminated phenolic, with laminations such as to produce edgewise compression. Stave details and clearances are shown in BUSHIPS Standard Plans S2200-921759 and S2200-921760. Clearances are also shown in BUSHIPS Technical Manual Chapter 41. Allowable compressive stress is taken as 3000 p.s.i. This material has a Young's modulus of about 420,000 p.s.i., and can run in water, grease, or oil. Commercial forms are sold such as Westinghouse Marine Micarta, Ryertex, and Tufnol. In special cases where laminated phenolic bearings sould be so long as to cause binding from flexure of the rudderstock, other materials are in order, such as gun metal or cobalt-base alloy. These permit higher bearing stresses, so they can be shorter. Typical installations are shown in BUSHIPS Plans SS564-S1108-935524 and SSN585-518-1713907. A calculation for clearance in the bearing with the stock in its deflected shape is shown in plan SSN585-845-1716223.

7.5 Anti-friction bearings are fairly expensive and require some precision machining to install. They have the compensatory advantages of permitting significant reduction of steering gear torque (in the order of 40%) and can be self-aligning (so that rudderstock deflections and hull movement do not cause binding). There are several manufacturers of roller bearings (spherical and non-spherical), which tends to keep the price reasonable. We usually require that the roller bearing vendor indicate his approval of the shipyard's installation details by signing on the working plan.

7.6 It is understood that roller bearings were installed on a collier at about the time of World War I, and that they had to be replaced by sleeve bearings. No records are available. USS TIMMERMAN (EDD 828) had a roller bearing installation which gave no trouble during the ships brief career at sea. USS NORFOLK (DL1) and the USS MITSCHER (DL 2) Class have spherical roller bearings which have been operating since about 1950. There had been some concern as to possible Brinelling of one or two rollers, due to pounding of a propeller race on a rudder which is generally operating near zero degrees. This has apparently not happened.

7.7 Two unsettled questions on *anti-friction* bearings are: (a) is it worthwhile requiring an installation with inner race expanded to take up clearances? and, (b) should designs call for an adapter so as to try to standardize on the bearing size? Past practice has permitted builders to use their judgement on these matters, and the actual practices vary. As service experience accumulate, the Ship Specifications can become more specific.

Section 8. - Bearing Seals

8.1 *Sleeve bearings at the hull can* operate with sea water as the lubricant. Usual practice, however, is to call for pressure grease lubrication and a seal. The seal is usually a gland, made in halves to facilitate replacement, with a few rows of packing. It is adjustable only in drydock. It more-or-less retains the grease and excludes sea water and sand or mud particles.

8.2 Sleeve and roller bearings within the hull are usually pressure grease lubricated, and occasionally oil lubricated. Adjustable seals are provided, and made in halves to facilitate unshipping.

8.3 Roller bearing seals at the hull require special attention because sea water will ruin the bearings. The DL1 and the DL2 Class have Syntron seals, adjustable only in drydock. These seals have an internal oil pressure which exceeds the sea pressure, so that if there is any leakage it will be oil going out. There was some difficulty in the building yards, due primarily to the attempt to wrap a straight extruded seal around a stock. When molded circular seals were used there were no problems. These Syntron seals have been operating satisfactorily on DL1 and DL2 for about 15 years. A more conservative solution has been used on recent destroyers, whereby the hull seal is a gland with packing, adjustable from inside the ship. This means moving the hull roller bearing upwards a little, with a slight increase in rudderstock bending moment. This type of seal has the advantage of being capable of repair almost anywhere.

Section 9. - Rudder Streamline Sections

9.1 Present practice is to specify the NACA 4-digit symmetrical series. Offsets are available in General Specifications 9220-1. The first two digits in this series are zero, and the last two digits represent the thickness/chord ratio (e.g. an 0024 section has thickness equal to 24% of the chord).

9.2 At the after edge, the offsets show a definite half-breadth. The trailing edge is specified to be left sharp, since this slightly improves lift, does not add to the cost, and provides a little extra strength (particularly for astern operation) compared with a knife edge.

9.3 Usual practice is to specify sections at the root and tip chord, with straight lines connecting like-numbered stations. Unless the thickness-chord ratios tip and root are identical, this results in a slightly warped surface. None of the shipyards have ever complained of this, and apparently the warp can be taken up, even with STS or HY80, without difficulty.

9.4 Some previous designs (e.g. MSO421 Class) had streamlined shapes to DTMB's EPH (ellipse-parabola-hyperbola) section. This practice was discontinued when it was learned that the EPH section had high negative pressure peaks at large angles of attack, and would thus be more likely to cavitate than the NACA section.

Section 10. - Rudder Initial Zero Setting

10.1 The rudder indicator zero in the pilothouse is sometimes set with the rudder not parallel to the center-line plane of the ship.

10.2 For twin-screw twin-rudder ships, model tests are ordered to determine SHP to make some high speed in the region of full power. These tests are run over a range of rudder settings-(both rudders with trailing edges inboard 4° to both with trailing edge outboard 4°.) The selection is made on the basis of lowest SHP to make desired speed but vibration sometimes is involved. On DD931 Class it was found that optimum rudder settings for propulsion involved unacceptable vibration. The rudder initial settings were modified to ease vibration, at the expense of propulsion. On DLG14 a similar condition was specifically investigated during builder's trials, and a similar compromise made. (See Code 442 rudder files for these ships).

10.3 For ships with single right hand screw, there is a basic tendency to turn to port. For such designs, model maneuvering tests are sometimes ordered to find the rudder angle for straightaway motion. The rudder is then set that way with indicators at zero.

10.4 For twin-rudder twin-screw ships, TMB model tests show that the best setting for minimum SHP is not the same as the best setting for minimum rudder drag. Presumably there is an interaction between propeller and rudder.

Section 11. - Astern Operation

11.1 Astern operation is usually investigated only for ships having a military requirement for going astern (e.g. LCU types which retract astern). Model tests are then used for determining controllability, since there is no reliable theory.

11.2 Ship speed for astern operation is usually estimated at 80% of the ahead speed for the same SHP. This is based on model tests of IFS1. If a more refined estimate is needed, propulsion tests should be ordered.

11.3 Astern operation generally does not control scantlings, and generally does control steering gear capacity. Recent practice has been to design the steering gear for ahead operation and limit sustained astern RPM so as not to exceed the steering gear capacity. "Sustained" astern RPM is specified so as to still permit the ship to use full astern RPM for crashback. It should be noted that for astern operation the hydrodynamic forces tend to move the rudder to larger angles, since the center of pressure is well aft of the stock. Accordingly, in going astern with a hydraulic system, when the relief valve opens, the rudder would go to hard over. To avoid this, usual practice is to specify that

the safe sustained astern RPM be determined from sea trials, and that suitable warning plates be installed.

11.4 Astern force and center of pressure coefficient for certain rudder shapes are available in Appendix C of DATMOBAS Report 933.

B. Submarine Control Surfaces

Practice:

Section 1 - General

1.1 Information in "Technical Practices - Rudder Design" is applicable also for submarines. Additional special items, pertinent only to submarines, are included here.

Criteria:

Section 2 - Stability and Control

2.1 The basis intent of submarine control surface design is to obtain positive directional stability, good depth and course keeping ability, and good ability to initiate and check trajectory changes. The preliminary design estimates of required control surfaces are generally tested by DTMB, and adjustments made as necessary. After minimum requirements are met, there is the problem of how much better to make performance. There is no fixed practice on this matter of degree of controllability. Design decision involves judgment, experience, and compromise related to the specific case.

2.2 Stability and control are design requirements for ahead operation, surfaced and submerged. Astern operation is generally quite unstable, and we accept whatever comes out of the design that has been based on ahead operation.

2.3 Basic theory for submarine stability and control is available in the Taylor Model Basin lecture notes "The Dynamical Stability of Submarines" by M. A. Abkowitz, June 1949. Another very good source of stability and control practice is in TMB reports on model tests and full scale evaluation of specific designs. These reports generally include considerable discussion of design suitability in addition to test data.

2.4 Performance requirements for automatic or semi-automatic control systems are specified in terms of "percentage of time within ± 5 foot band" at particular speed (e.g. 6 knots) and keel depth (periscope depth) in a particular sea state. Computer studies using model data are run at DTMB to determine the practicality of the specification.

Section 3 - Fairwater Planes and Bow Planes

3.1 Fairwater planes (also called sail planes) or bow planes are provided primarily for assisting the stern planes in low speed fine control of depth (e.g., 4 knots and periscope depth). In cases of stern plane jamming at small angles, the forward planes could overpower the after ones and control depth and pitch angle. In usual design practice, however, the forward planes are not made large enough to be effective in such emergencies. Some submarine operators use bow planes for depth-changing at high speed, but this is not general practice. ALBACORE (AGSS 569) evaluated performance with and without bow planes, and, for her operations, finally concluded they should be omitted. AGSS 555 is being build without bow or fairwater planes, since the ship characteristics do not require fine depth control and the omission reduces weight, cost, and mechanical complexity.

3.2 Bow planes, situated as far forward as possible, have greater pitching leverage than fairwater planes. In such forward locations bow planes have had to be stowed by folding or rotating, since their outreach would make handling at docks and resting quite difficult and also to avoid pounding when surfaced in a seaway. Recent designs (SS(N)585, SSB(N)598 and 608) call for fairwater planes primarily to release the valuable space forward for sonar and torpedoes. Fairwater planes outreach is usually kept within maximum hull dimensions, and rolling alongside a dock is also considered (e.g., see Code 442 file for SS(N) 597). Fairwater planes are incidentally used as a gangway for access. Sockets for portable stanchions are fitted with faired plugs for operation at sea.

3.3 The leading edge is usually raked so as to deflect mine cables. There is no fixed practice on whether tips should be square (cheaper and more lift) or rounded (costlier, less lift, somewhat quieter).

3.4 In computing forces and centers of pressure, the angle of attack is taken as the plane angle. (Unlike Rudder Design Practice, Section 3.3, the diving planes can be operating with no drift angle reduction.) The usual plane angle is limited to 20° or 25°; based on estimated stall.

3.5 Fairwater or bow plane tilting rate is usually taken equal to that for the stern planes.

3.6 The height of fairwater planes is of considerable importance. SSB(N) 608 and 616 Class planes are about four feet higher (relative to optics and electronics masts) than SSB(N) 598 Class. This has led to greater difficulties in periscope-depth

control is a seaway than for 598 Class. The separation between periscope and fairwater planes on SS(N) 585 Class appears satisfactory. As an experiment, bow planes have been installed on SSB(N) 626. Evaluation thus far is not conclusive since there are some subjective factors and the seaway involves a variable test environment.

Section 4 - Stern Planes and Stabilizers

4.1 The area needed at the stern for stability in the vertical plane is determined by theory (Code 421 has the best information on prediction methods) and model test. The area is usually too large to be made all-movable, so part of it is installed as a fixed stabilizer. At times fixed area is inserted on shaft lines of twin screw subs (e.g., SS(N)571).

4.2 As with bow planes, the angle of attack is taken equal to the plane angle, without any drift corrections. The force and center of pressure determination for the stern plane plus stabilizer combination is lengthy and complex. The best sources of force and torque information are the Code 442 file, "Rudders and Diving Planes SSB(N)608" (which includes reference material), and recent research reports by Georgia Institute of Technology on "Wind Tunnel Investigation of the Effect of a Simulated Submarine Hull on the Aerodynamic Characteristics of All-Movable Control Surfaces Having NACA 0015 Airfoil Sections" dated August 1959, and by U. of Maryland on "Wind Tunnel Investigation of the Characteristics of a Flapped Control Surface Mounted on a Simulated Submarine Hull" dated June 1959. These reports are available in Code 442 file "Fluid Mechanics - Control surfaces".

4.3 The planform and location of stern plane and stabilizer are selected with the following considerations in addition to conventional hydrodynamic efficiency:

(a) The leading edge rake should be such as to deflect mine cables, or else the shape should permit attaching cable guards.

(b) Ample fore-and-aft clearance from the propeller should be maintained, to minimize noise and vibration. Clearance is measured from the centerline of propeller blade at the 0.7 radius to the leading edge of the control surface, and is non-dimensionalized in the form of percent of propeller diameter.

(c) Span should be limited so as to facilitate nesting, coming alongside a dock, and for larger subs to increase the number of drydocks and building ways that can be used. The SSB(N)608 stern planes and stabilizer have an over-all span of 40'-4", which is about the limit on Electric Boat Division's building ways. This span extends beyond the maximum beam (pressure hull diameter - 33'-0"), but is necessary for stability and control. Portable outboard sections of stabilizers are permissible where necessary for building ways clearance.

4.4 Stern plane tilting rate is generally specified as 5°/sec. minimum, to provide adequate controllability, and 10°/sec. maximum, to minimize the required capacity of the hydraulic system. A more refined specification is shown in the Preliminary Design section on technical practices for hydrodynamics. The most reliable method of specifying stern plane rate is from a computer study of its effect on trajectories or depth control in a seaway.

4.5 Since the stern planes are vital for depth control, particular emphasis is placed on minimizing corrosion of the stocks. We require protective coatings on exposed portions, and there is a routine requirement for periodic inspection. At present this problem is not satisfactorily solved. New coatings are being tried, and we keep up with the latest service experience obtainable from the Submarine Ship Type Branch.

Section 5 - Rudders

5.1 The design of submarine rudders is generally the same as covered in "Technical Practices - A. Rudder Design". The significant differences are discussed below.

5.2 A top-side rudder is in a flow which has been disturbed by the sail and superstructure. This was first demonstrated by a wake survey on a model of SSB(N)608. Accordingly, the top-side rudder is not very effective for stability, where small angles are involved, even though quite effective for turning. A large fixed stool support for the upper rudder was used on SSB (N)608, to get the upper rudder into a cleaner flow region.

5.3 A dorsal rudder (see plan AGSS569-800-1934050 is a flap on the after end of the sail, designed to reduce snap roll in submerged turns. As a submarine goes into a turn, the angle of attack on the sail would produce lift causing large inward heel. The dorsal rudder introduces a camber which reduces the undesirable lift on the sail. Timing the movement of the dorsal and conventional rudders is important in achieving this. Dorsal rudders are still considered experimental, and USS ALBACORE (AGSS569) represents the only application at present.

5.4 For AGSS 555, rudder plating and stiffeners are of fiberglass reinforced plastic. Rudders were fabricated by Republic Aviation Corp. for

Portsmouth Naval Shipyard, and are filled with syntactic foam. In this application fairly thick rudders, NACA 0020, are specified in order to provide buoyancy. Service experience is desirable before further applications.

Section 6 - Initial Zero Settings

6.1 The diving plane initial settings involve indicator zero even though planes may be tilted relative to baseline. Settings are selected on the basis of model tests so as to produce steady flight at constant depth at significant speeds. A small hull angle is generally accepted rather than take the higher plane drag needed for zero boat angle. For example, on USS Triton (SSR(N)586), the bow planes are set parallel to base line, the stabilizers and stern planes are set one-half degree rise, and the estimated hull angle is one degree down (at higher speeds).

6.2 On single screw subs the stern planes and rudders are also set at an angle so as to counteract the propeller torque. Theoretically the setting is independent of ship speed, since control surface lift and also propeller torque are both proportional to square of speed. (Some anomalous results, reported by Portsmouth from Builders Trials of USS BARBEL (SS580) are not considered in setting controls for single screw boats). These settings for counteracting propeller torque are in the right direction for acting as guide vanes to the propellers aft of them. The stern plane angles for countering propeller torque are combined algebraically with those for flight at constant depth. On SSB(N) 598 class, with a single right-hand propeller, the net result was to require the port stern plane to be set at 2° 30′ dive, the starboard stern plane at 0° 30′ dive, the upper rudder 1° trailing edge to port, and the lower rudder 1° trailing edge to starboard.

Section 7 - Sea Slap

7.1 The practice is to assume that waves acting on exposed control surfaces are equivalent to a static uniform load of 1000 pounds per square foot. Under this loading the Ship Specifications usually indicate that

(a) Structure may be stressed up to the yield point (this particularly involves torque keys and keyways).

(b) The control surface torque may exceed hydraulic gear capacity (because of the long lever arm to sea slap center of pressure).

In that case, popping the relief valve is acceptable. On SS(N)597 the Electric Boat Division made a computer analysis of the response of the hydraulic system to such transient loading. For that purpose we arbitrarily indicated that the loading could be taken as

$$1000 \sin \frac{2 \pi T}{0.2} \text{ lbs/sq. ft. where}$$

T varies from 0 to 0.2 seconds

7.2 The 1000 p.s.f. comes from a 1924 Portsmouth analysis of casualties to bow and stern planes of the S-48 to 51 and T-1 to 3 classes, due to pounding in a seaway. Although it is recognized that sea slap can be several times greater than 1000 p.s.f. it is implicitly assumed that in very rough weather the submarine will submerge.

Section 8 - Bearings

8.1 Departures from practice listed in "Technical Practices - Rudder Design" are as follows:

(a) Laminated phenolic bearings are not commonly used on submarines.

(b) Anti-friction (roller) bearings are not used for radial loads. Gun metal and cobalt base alloy (such as made by the Stoody Co.) are the usual materials for radial loading.

(c) Rudder carrier bearings take thrust in a free-flooding space. They are made of nickel-copper silicon alloy (S-monel or else of nickel copper aluminum alloy K-Monel). A typical installation is shown in plan SSR(N)585-519-1717598. Less costly materials have been tried in the past but did not give satisfactory service.

Section 9 - Filling Material

9.1 Until about 1957 the only filling material for submarine control surfaces was wood, plus hot vegetable pitch to fill interstices.

9.2 Present practice also permits use of foamed-in place plastics, which are expected to be cheaper. In order to get high crushing strength as needed for deep submergence, the density and the water absorption of the plastic must be carefully selected.

Section 10 - X-Stern

10.1 The x-stern of ALBACORE has been tested, and results are available in formal DTMB classified reports. In brief, the x-stern:

(a) solves the problem of getting adequate rudder effectiveness without exceeding hull block dimensions,

(b) provides increased safety in case one ram jams hard over (per DTMB letter noted in 11.1)

(c) adds some complexity to the controls,

(d) provided more diving plane effectiveness than desirable at high speeds.

Section 11 - Dive Brakes

11.1 Dive brakes were tested at sea as part of the ALBACORE Phase 3 conversion trials. DTMB Confidential Letter Report 09080 ALBACORE (546:

PCC:jw) Ser. 0516 of 8 May 1962 to BUSHIPS Code 525 gives results. In brief, the brakes make an appreciable contribution to deceleration. In future designs, it will be desirable to obtain a computer prediction of emergency recovery trajectories for various dive brake configurations before ordering installation.

APPENDIX G

Computer Program Documentation for Rudder and Fairwater Plane Design

Description

A. Purpose

The purpose of this program is to aid the designer in the design of rudders and fairwater planes. In particular the program does the following things:

1. Given an initial geometric configuration the program determines a stock location and stock diameter which minimizes the differences between the positive and negative torques.

2. During this process the program also determines reaction forces at the bearings and prints them out.

B. General Method

The general philosophy of the calculations in this program is the minimizations of the difference between the most positive torques and most negative torques. These torques are calculated at different deflection angles of the control surface and the largest positive one is compared with the most negative one. The stock location, which gives the difference which is less than some fixed epsilon, is the answer. With each stock location and the torques computed, an appropriate stock diameter is determined. The details are somewhat more complicated than this brief outline indicates.

11

Production Details

A. Program Restrictions

1. The number of deflection angles must be = 20.

2. The number of iterations must be = 50.

3. A realistic initial geometric configuration must be used. e.g., a zero initial stock diameter cannot be used.

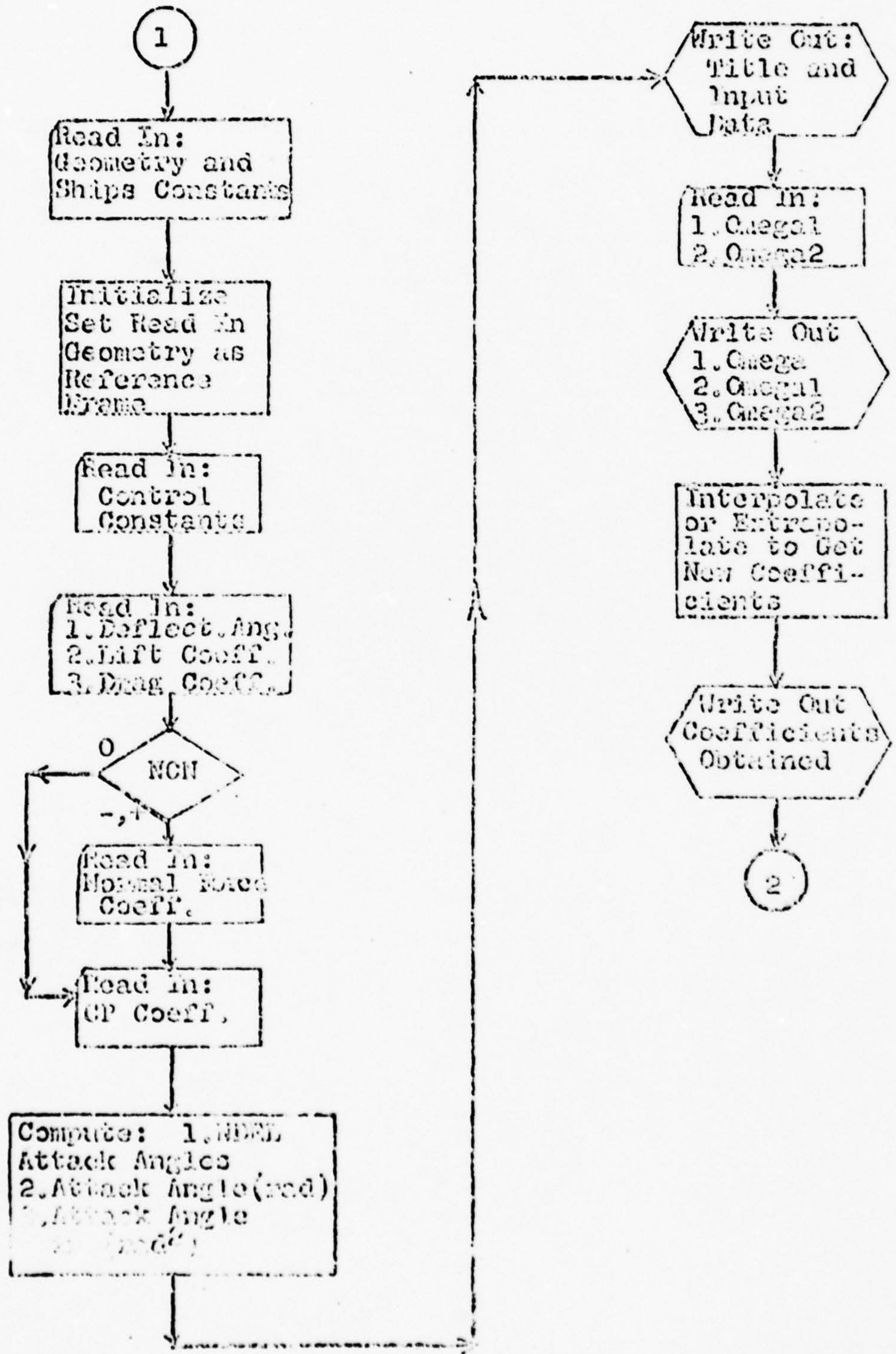
4. The program uses $(1563)_{10}$ storage locations. The program break occurs at $(4472)_{10}$. The common break occurs at $(75413)_8$.

5. Given one initial configuration (one set of data), the program will make 5 iterations in at most 5 centihours.

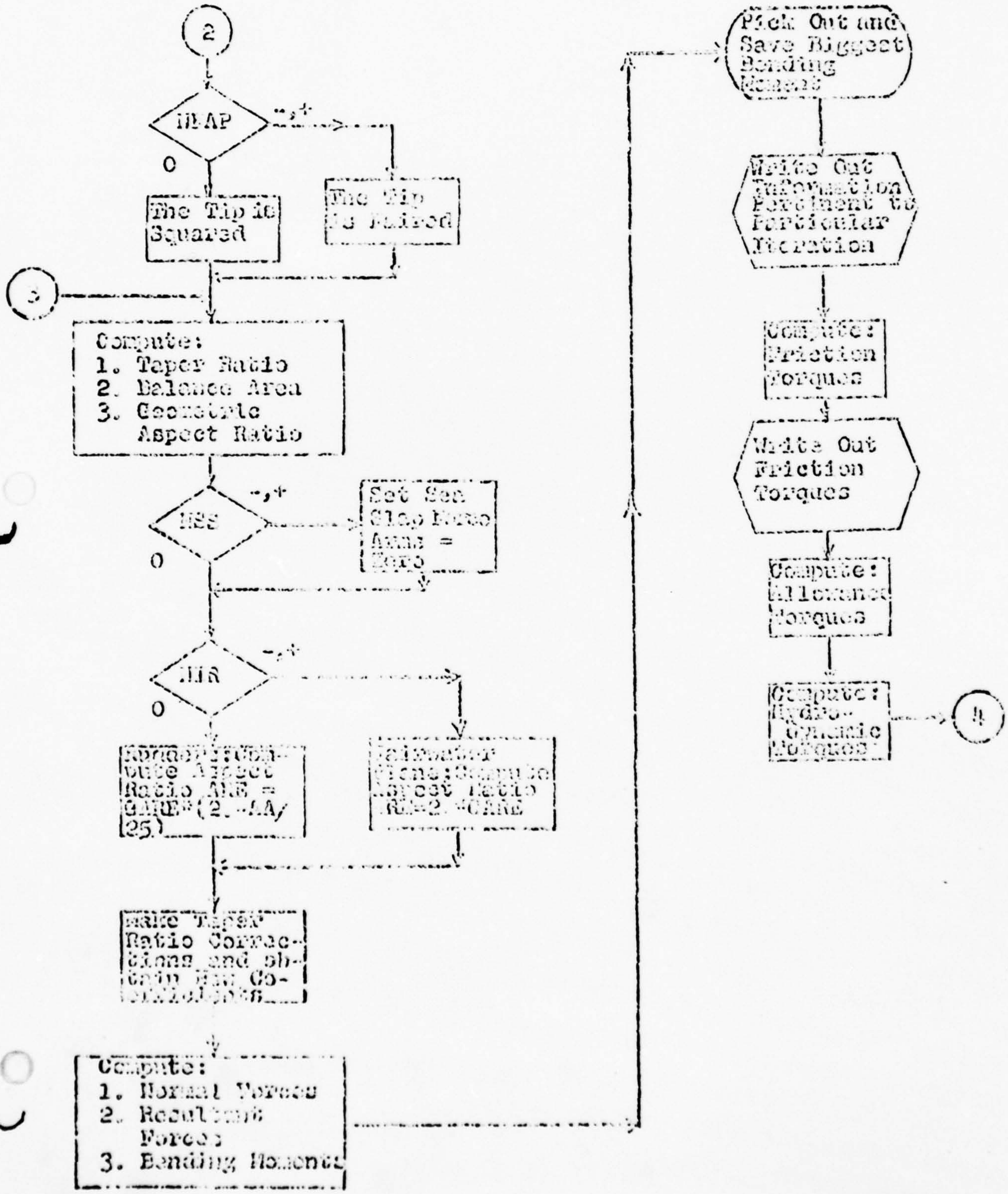
6. Due to the nature of the problem and the method of false position many more than 8 iterations will probably give incorrect results.

7. The program will handle more than one set of data at a time.

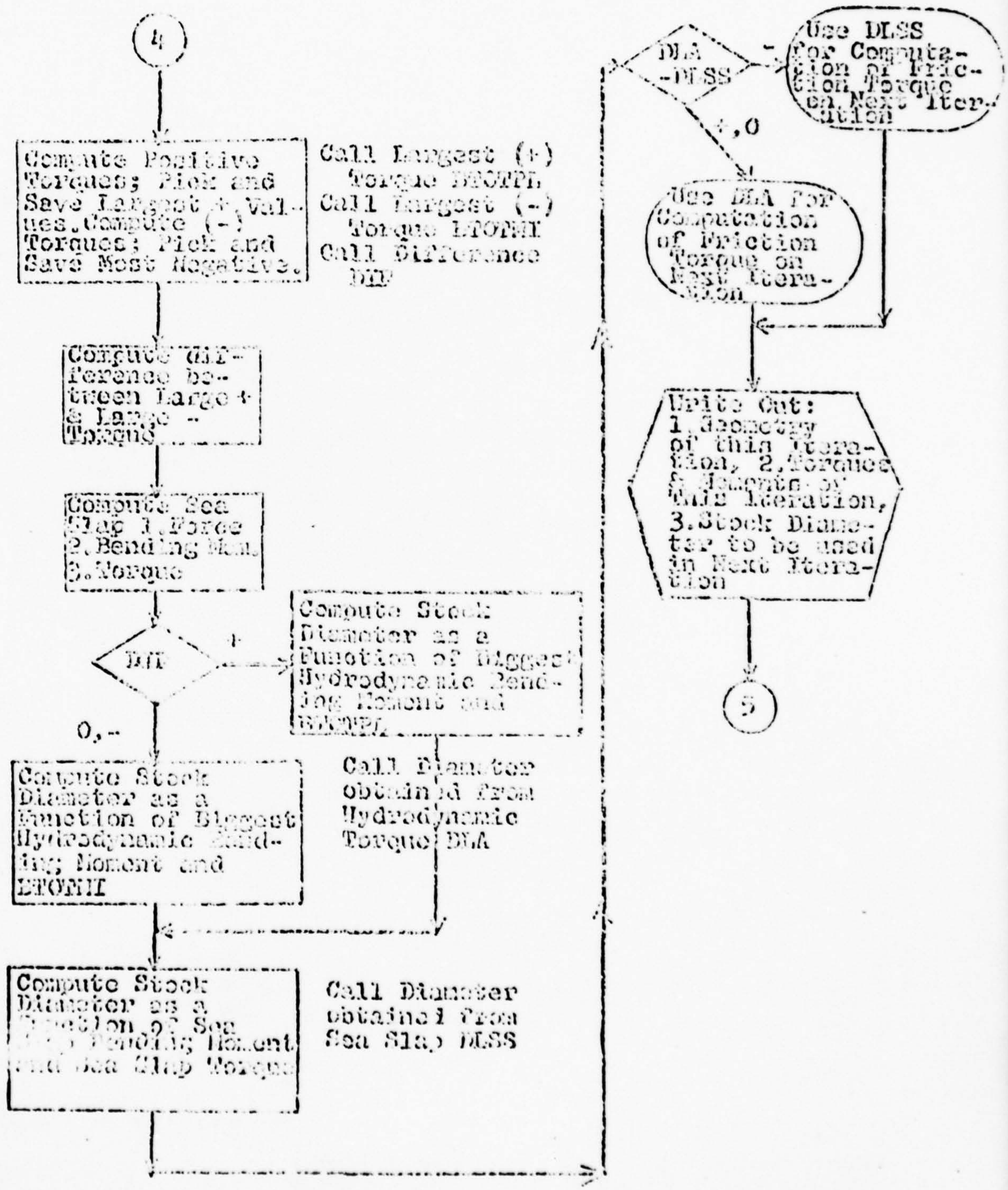
B. Flow Chart for Rudder and Fairwater Plane Calculations



<u>Note</u>: Torques, Forces, and Bending Moments are computed for each Attack Angle.



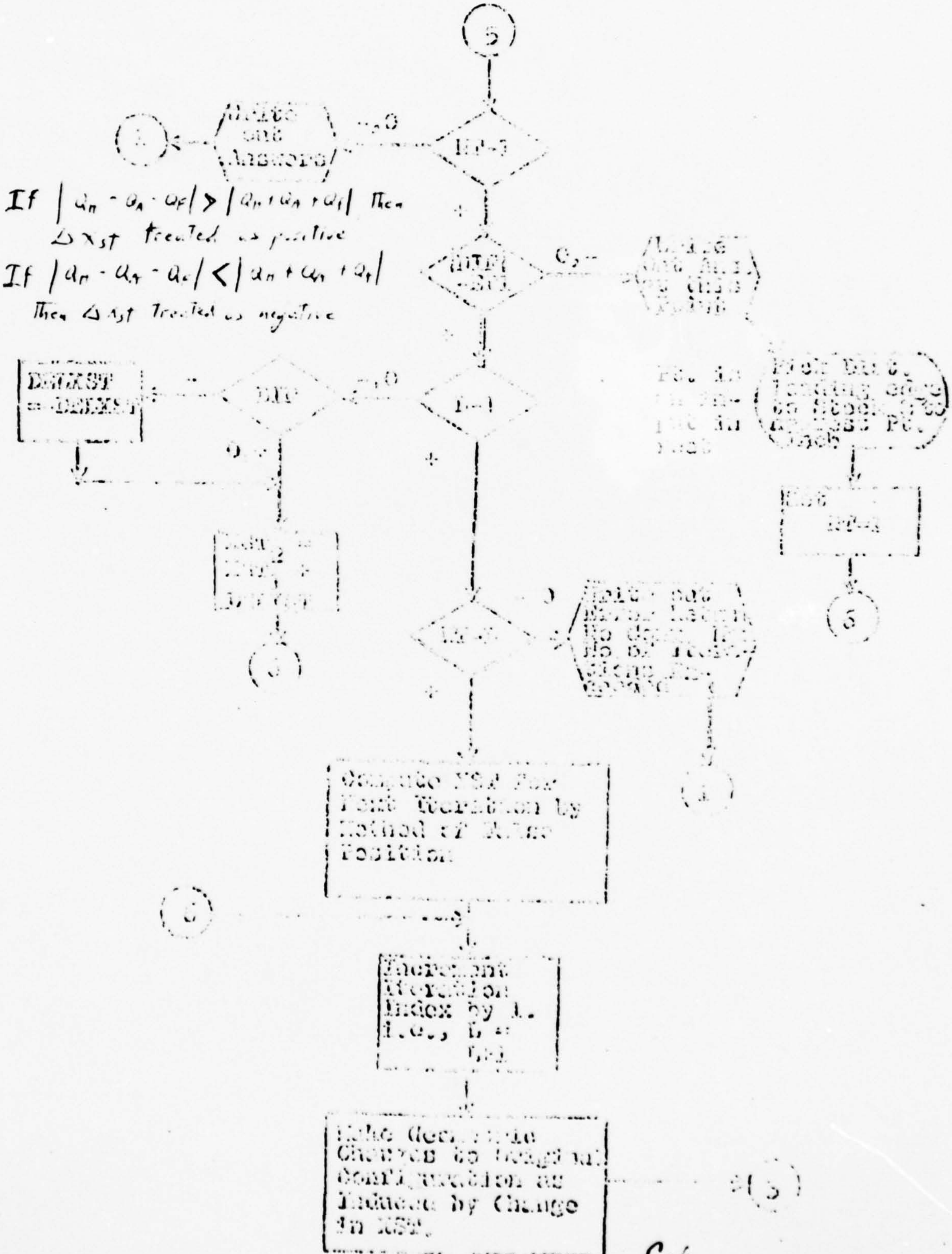
G4


4
Compute Positive Torques; Pick and Save Largest + Values. Compute (-) Torques; Pick and Save Most Negative.
Call Largest (+) Torque BTOTPL
Call Largest (-) Torque BTOTMI
Call Difference DIF
Compute difference between Large + & Large - Torque
Compute Sea Slap 1.Force 2.Bending Mom. 3.Torque
DIF
+
0, -
Compute Stock Diameter as a Function of Biggest Hydrodynamic Bending Moment and BTOTPL
Compute Stock Diameter as a Function of Biggest Hydrodynamic Bending Moment and BTOTMI
Call Diameter obtained from Hydrodynamic Torque DLA
Compute Stock Diameter as a Function of Sea Slap Bending Moment and Sea Slap Torque
Call Diameter obtained from Sea Slap DLSS
DLA -DLSS
-
+,0
Use DLSS for Computation of Friction Torque on Next Iteration
Use DLA for Computation of Friction Torque on Next Iteration
Write Out: 1.Geometry of this Iteration, 2.Torques & Moments of this Iteration, 3.Stock Diameter to be used in Next Iteration
5

Note: "DELXST" is input increment to distance from leading edge to stack G. XST is the distance. L is iteration index.

If $|a_n - a_A - a_f| > |a_n + a_A + a_f|$ Then ΔX_{st} treated as positive

If $|a_n - a_A - a_f| < |a_n + a_A + a_f|$ Then ΔX_{st} treated as negative



G-6

C. Programmed and Mathematical Notation

(Input variables are defined in preparation of input)

Mathematical Notation		Programmed Notation
A_T	Total Area	AT
A_{Fwd}	Forward Area	[illegible]
A_{Aft}	Aft Area	[illegible]
β	Hull Slope Angle	[illegible]
C_R	Root Chord	[illegible]
C_T	Tip Chord	CT
C_M	Mean Chord	CM
X_{st}	Lead Edge to Center Line of Stock	XST
TECL	Trailing Edge to Center Line of Stock	TECL
[illegible]	X_{st}/C_M	[illegible]
D_{1A}	Stock Diameter	[illegible]
Ω	Sweep Angle of 1/4 Chord	[illegible]
S	Span	[illegible]
A_e	Effective Aspect Ratio	[illegible]
A	Aspect Ratio	[illegible]
λ_2	Taper Ratio	[illegible]
V	Ship Speed	V
ρ	Density = 1.98	RHO
C_{DC}	Cross Flow Drag	[illegible]
	Coefficient	[illegible]
$(C_L)_2$	Final Lift Coefficient	[illegible]
$(C_D)_2$	Final Drag Coefficient	[illegible]
$(C_N)_2$	Final Normal Force Coefficient	[illegible]

G 7

Mathematical Notation		Programmed Notation
$(C_P)_2$	Final Pressure Coefficient	CP2
$(C_R)_2$	Final Resultant Force Coefficient	CR2

Note: Each of these coefficients go through phases. There are inputs which are interpolated to get a first approximation and then a taper ratio correction is performed giving these final coefficients. The taper ratio correction is also made after each geometric change.

δ_2	Deflection Angle	ADEL
α	Attack Angle	AA
δC_L	Computed	DELCL
δC_D	Computed	DELCD
$(C_{PC/4})_1$	1/4 Chord Pressure Coefficient	CPC41
$(C_{MC/4})_1$	1/4 Chord Mean Coefficient	CMC41
$(C_{PC/4})_2$	1/4 Chord Final P Coefficient	CPC42
$(C_{MC/4})_2$	1/4 Chord Final M Coefficient	CMC42
(C_{PLE2})	Same as CP2 above	CPLE2
BL	Length between Bearings	BL
BPL	Center of Pressure to Near Bearing	BPL
D_i/D_o	Inner Diameter/Outer Diameter	DD
D_o/D_n	Other Diameter/Near Diameter	OND
F_N	Normal Force	FN
F_R	Resultant Force	FR

Mathematical Notation		Programmed Notation	
C_{FU}	Friction Coefficient Other Bearing	CFU	
C_{FL}	Friction Coefficient Near Bearing	CFL	
Q_F	Friction Torque	QF	
Q_H	Hydrodynamic Torque	QH	
Q_{A+}	Plus Allowance Torque	QAPL	
Q_{A-}	Minus Allowance Torque	QAMI	
$Q_H+Q_F+Q_{A+}$	Positive Torques	TQPL	
$Q_H-Q_F-Q_{A-}$	Negative Torques	TQMI	
$+Q_E$	Positive Allowance	QE	
$-Q_E$	Negative Allowance	QE2	
F_{SS}	Sea Slap Force	SFS	
BM_{SS}	Sea Slap Bending Moment	BMSS	
Q_{SS}	Sea Slap Torque	QSS	
$\lvert Q_H+Q_F+Q_{A+}\rvert_{max} - \lvert Q_H-Q_F-Q_{A-}\rvert_{max}$	Maximum Torque Difference	DTF	
RR	ratio of Area in Race	RR	$0 \leqq RR \leq 1$
SLIP	Propeller Slip	SLIP	
$F_{(reac.)n}$	Reaction Force on Near Bearing	FL	
$F_{(reac.)o}$	Reaction Force on Other Bearing	FU	

Physical Quantity	Dimensions
Areas	Square Feet
Lengths	Feet
Forces	Pounds
Torques	Inch-pounds
Moments	Inch-pounds
Yield Stress	PSI
Velocity	Knots
Density	Pound-second/(feet)^4

Note: All conversions to make dimensions compatible C 7

D Data Preparation

			Format
Card 1	Title	72 BCD characters	12A6
Card 2	Title	72 BCD characters	12A6
Card 3	AINIT	Initial Total Area (sq.ft.)	E13.7
	AIFWD	Initial Fwd. Area (sq.ft.)	E13.7
	AIAFT	Initial Aft Area (sq.ft.)	E13.7
	AS1	Spare	E13.7
	AS2	Spare	E13.7
Card 4	CR	Initial Root Chord (ft.)	E13.7
	CT	Initial Tip Chord (ft.)	E13.7
	SLOPCH	Chord for Changing Area (ft.)	E13.7
	SPC	Span for Changing Bal. Area (ft.)	E13.7
	CS2	Spare	E13.7
Card 5	BPL	Spare	E13.7
	BL	Distance between Bearings (ft.)	E13.7
	SPAN	Initial Span	E13.7
	Z1	Spare	E13.7
	Z2	Spare	E13.7
Card 6	CFL	Brng. Friction Coeff. (near Brng.)	E13.7
	CFU	Brng. Friction Coeff. (other Brng.)	E13.7
	SPWCPC	Spanwise CP Coefficient	E13.7
	C1	Spare	E13.7
	C2	Spare	E13.7
Card 7	SF1	Safety Factor 1 (Hydrodynamic)	E13.7
	SF2	Safety Factor 2 (Sea Slap)	E13.7
	QE	Positive Allowance Factor	E13.7
	QE2	Negative Allowance Factor	E13.7
	SLRT	Slip Ratio	E13.7
Card 8	RR	~~Percent~~ Rotor Area in Race	E13.7
	E	Taper Ratio Factor E	E13.7
	DLMULT	Multiplier to get Attack Angle	E13.7
	Z3	Spare	E13.7
	Z4	Spare	E13.7

(Usually 0.7143 = 5/7 for Rudder
1.0 For FW Plane)

			Format
Card 9	SLO	Initial Stock Location (Ratio)	E13.7
	DELXST	Initial Distance Change Leading Edge to Stock CL. (ft.)	E13.7
	DIAMIN	Initial Stock Diameter in.)	E13.7
	EP1	Epsilon for Unbalance (inch-lb.)	E13.7
	EP2	Spare	E13.7
Card 10	CPSS	Initial Center of Area to Near Brng. (ft.)	E13.7
	ARMS	Initial Center of Area to Stock CL. (ft.)	E13.7
	SY	Yield Stress (PSI)	E13.7
	DD	Inner/Outer Diameter Ratio	E13.7
	DUD	Other/Near Diameter Ratio (When using 2 bearings for one control surface use 2 brng friction coeffs)	E13.7
Card 11	BETA	Hull Slope Angle (deg.)	E13.7
	OMEGA	Sweep Angle of 1/4 Chord (deg.)	E13.7
	RHO	Density lb-sec^2/ft^4	E13.7
	V	Velocity (knots)	E13.7
	DR13PT	Initial Distance from Root to 1/3 Point of Brng. + if Inboard of Root - if Outboard of Root (ft.)	E13.7
Card 12	STH	Stock Sleeve Thickness (in.)	E13.7
	SPHD	Spherical Diameter Factor	E13.7
	PT	Program computes to nearest Pt. inches (feet) .0104167' (1/8")	E13.7
Card 13	NDEL	Number of Deflection Angles	I4
	NT	Max. Number of Iterations	I4
	NT1	Spare = 0	I4
	NFAP	= 0 Squared Tip = 1 Faired Tip	I4
	NSS	= 0 Consider Sea Slap = 1 Don't Consider Sea Slap	I4
	NCN	= 0 Calculate CN 1 = 1 Read in CNLOW and CNH1 and Interpolate for CN1	I4
Card 14	NIR	= 0 for Rudder calculations — $AR_e = AR_g\left(2 - \frac{a}{25}\right)$ = 1 for Fairwater Planes — $AR_e = AR_g$	I4
	NDO	Spare = 0	I4
	NX1	Spare = 0	I4
	NX2	Spare = 0	I4
	NX3	Spare = 0	I4
	NX4	Spare = 0	I4
Cards 15	ADEL(NDEL)	NDEL Deflection Angles (degrees) Usually 0, 7, 14, 21, 28, 35 deg (for rudders)	6E13.7
Cards 16	CLLOW(NDEL)	NDEL Low Lift Coefficients	6E13.7

			Format
Cards 17	CLHI(NDEL)	NDEL High Lift Coefficients	6E13.7
Cards 18	CDLOW(NDEL)	NDEL Low Drag Coefficients	6E13.7
Cards 19	CDHI(NDEL)	NDEL High Drag Coefficients	6E13.7

<u>If NCN = 1</u>

Cards 20	CNLOW(NDEL)	NDEL Low Normal Force Coeff.	6E13.7
Cards 21	CNHI(NDEL)	NDEL High Normal Force Coeff.	6E13.7

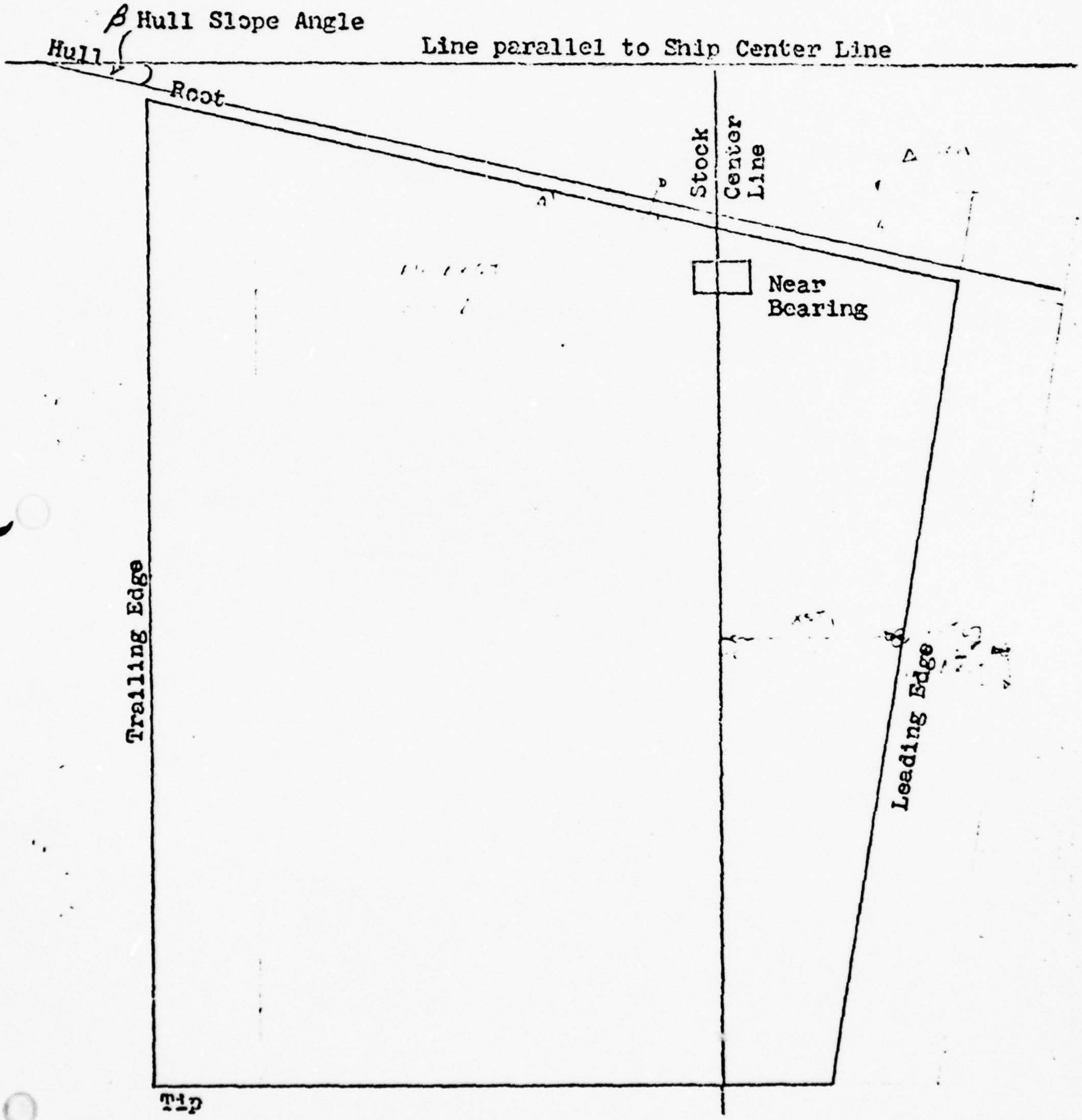
Go to Cards 22

<u>If NCN = 0</u>

Cards 22	CPLOW(NDEL)	NDEL Low CP Coeff.	6E13.7
Cards 23	CPHI(NDEL)	NDEL High CP Coeff.	6E13.7
Cards 24	OMEGA1	Low Angle for Coeff. (deg.)	E13.7
	OMEGA2	High Angle for Coeff. (deg.)	E13.7

E. Figure 1 - Rudder or Fairwater Plane

The tip may be faired or squared.



Note: Near Bearing may be inside or outside of Root. Other bearings not shown in this picture. Center of pressure and center of area are defined from the geometry.

Appendix

Formats

A. The input format is exhibited on the following pages of this report.

B. A copy of the output of this program is filed with the Digital Computer Department.

UNIVAC [illegible] PROGRAM NO. 0305 - RUDDER AND FAIRWATER PLANES CALCULATION

Date
Shop Order
Work Order
Customer
Dwg.

Card

1) [illegible] Title - 72 BCD Characters - Centered Around Column 38

2) Title - 72 BCD Characters - Centered Around Column 38

3) [illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
CB	[illegible]	[illegible]	[illegible]	[illegible]
BPL	BL	SPAN	[illegible]	[illegible]
CPL	CPU	[illegible]	C1	C2
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

PROGRAM NO. 0305 - [illegible] CALCULATION

OMEGA

UNIV[illegible] 1107 PROGRAM NO. 0305 - RUDDER AN[illegible] [illegible]ERWATER PLANES CALCULATION

1	13	25	37	49	61	73
±.XXXXX	±XX ±.XXXXXX	±XX ±.XXXXXX	±XX ±.XXXXXX	±XX ±.XXXXXX	±XX ±.XXXXXX	±XX ±.XXXXXX ±XX

Cards

15-	ADEL(1)	ADEL(2)	ADEL(3)	ADEL(4)	ADEL(5)	ADEL(6)
(1-6)						
(7-12)						
(13-18)						
(19-20)						

16-	CLIGH(1)	CLIGH(2)	CLIGH(3)	CLIGH(4)	CLIGH(5)	CLIGH(6)
(1-6)						
(7-12)						
(13-18)						
(19-20)						

17-	[illegible](1)	[illegible](2)	[illegible](3)	[illegible](4)	[illegible](5)	[illegible](6)
(1-6)						
(7-12)						
(13-18)						
(19-20)						

1[illegible]-	[illegible](1)	[illegible](2)	[illegible](3)	[illegible](4)	[illegible](5)	[illegible](6)
(1-6)						
(7-12)						
(13-18)						
(19-20)						

There are [illegible] cards for [illegible] ... [illegible] to right starting with lowest deflection angle [illegible] ... must correspond to the correct deflection angle on all cards.

Page ___ of ___

[illegible] 1107 PROGRAM NO. 0305 - [illegible] FAIRWATER PLANES CALCULATION

[illegible]

19-	CDHI(1)	CDHI(2)	CDHI(3)	CDHI(4)	CDHI(5)	CDHI(6)
(1-6)						
(7-12)						
(13-18)						
(19-20)						

If NCN = 1 Fill out next two sets of cards as well as the rest.

If NCN = 0 Skip next two sets and fill out cards 22 through 24.

20-	CDLOW(1)	CDLOW(2)	CDLOW(3)	CDLOW(4)	CDLOW(5)	CDLOW(6)
(1-6)						
(7-12)						
(13-18)						
(19-20)						

21-	[illegible]	CLHI(2)	[illegible]	CLHI(4)	CLHI(5)	CLHI(6)
(1-6)						
(7-12)						
(13-18)						
(19-20)						

22-	CPLOW(1)	CPLOW(2)	CPLOW(3)	CPLOW(4)	CPLOW(5)	CPLOW(6)
(1-6)						
(7-12)						
(13-18)						
(19-20)						

[illegible] 1107 PROGRAM NO. 0505 - RUDDER [illegible] FAIRWATER PLANES CALCULATION

[illegible]

23)	CPHI	CPHI(2)	CPHI(3)	CPHI(4)	CPHI(5)	CPHI(6)
(1-6)						
(7-12)						
(13-18)						
(19-20)						

	OMEGA1	OMEGA2
(24)		

6-17

```
R 002321 AIFWD      0000 R 002320 AINIT     0000 R 000675 ARE      0000 R 002
  002323 AS1        0000 R 002324 AS2       0000 R 002403 AT       0000 R 0024
R 002456 BBM        0000 R 002370 BETA      0000 R 002406 BETAR    0000 R 002
R 002462 BMSS       0000 R 002332 BPL       0000 R 002460 BTOTMI   0000 R 0024
R 002445 CDC1       0000 R 002451 CDC2      0000 R 000315 CDHI     0000 R 000
R 001041 CD2        0000 R 002337 CFL       0000 R 002340 CFU      0000 R 0014
R 002414 CK5        0000 R 000245 CLHI      0000 R 000221 CLLOW    0000 R 0005
R 002417 CM         0000 R 001161 CMC141    0000 R 001231 CMC142   0000 R 000
R 000651 CN1        0000 R 001065 CN2       0005 R 000000 COS      0000 R 0011
R 000435 CPHI       0000 R 001255 CPLE2     0000 R 000411 CPLOW    0000 R 002
R 000601 CP1        0000 R 002325 CR        0000 R 002410 CRINIT   0000 R 0024
R 001301 CR2        0000 R 002331 CS2       0000 R 002326 CT       0000 R 002
R 002366 DD         0000 R 002473 DELAFW    0000 R 001015 DELCD    0000 R 0007
R 002472 DELTA      0000 R 002471 DELTH     0000 R 002357 DELXST   0000 R 002
R 002466 DL         0000 R 002415 DLA       0000 R 002265 DLAIR    0000 R 002
R 002374 DR13PT     0000 R 002367 DUD       0000 R 002352 E        0000 R 0023
R 002467 FALPO      0000 R 001421 FL        0000 R 001325 FN       0000 R 001
R 002453 GARE       0000 I 002317 I         0000 I 002413 L        0000 I 0024
I 002424 NDEL       0000 I 002433 NDO       0000 I 002427 NFAP     0000 I 0024
I 002425 NT         0000 I 002426 NT1       0000 I 002434 NX1      0000 I 0024
I 002437 NX4        0000 I 002432 N1R       0000 R 002443 ODEL     0000 R 0024
R 002441 OMEGA1     0000 R 002442 OMEGA2    0000 R 002400 PT       0000 R 0016
R 002346 QE         0000 R 002347 QE2       0000 R 001611 QF       0000 R 0017
R 002001 QHQAPL     0000 R 001755 QHQFMI    0000 R 001731 QHQFPL   0000 R 0024
R 001565 Q2         0000 R 002372 RHO       0000 R 002351 RR       0000 R 0024
  002345 SF2        0004 R 000000 SIN       0000 R 002375 SLIP     0000 R 0023
  002203 SLOIR      0000 R 002327 SLOPCH    0000 R 002350 SLRT     0000 R 002
R 002330 SPC        0000 R 002377 SPHD      0000 R 002341 SPWCPC   0000 R 0024
R 000531 SQRD       0006 R 000000 SQRT      0000 R 002376 STH      0000 R 002
R 000062 TECL       0000 R 000144 TITLE     0000 R 002075 TOTMI    0000 R 0020
R 002373 V          0000 R 002401 V2        0000 R 002454 XCD      0000 R 0024
R 000000 XST        0000 R 002316 ZLAM1     0000 R 002447 ZLAM2    0000 R 0024
R 002336 Z2         0000 R 002354 Z3        0000 R 002355 Z4
```

```
DIAGNOSTIC*   UNBAL APPEARED,BUT NEVER REFERENCED.
  1.          DIMENSION XST(50),TECL(50)
  2.          DIMENSION TITLE(25),ADEL(20),CLLOW(20),CLHI(20),
  3.         1CDLOW(20),CDHI(20),CNLOW(20),CNHI(20),CPLOW(20),CPHI(20),
  4.         2AA(20),AARAD(20),SQRD(20),CL1(20),CP1(20),CD1(20),CN1(20),
  5.         3ARE(20),DELCL(20),CL2(20),SQCLS(20),DELCD(20),CD2(20),
  6.         4CN2(20),CR1(20),CPC141(20),CMC141(20),CPC142(20),CMC142(20),
  7.         5CPLE2(20),CR2(20),FN(20),FR(20),BM(20),FL(20),FU(20),
  8.         6CK15(20),CK16(20),Q1(20),Q2(20),QF(20),QAPL(20),QAMI(20),
  9.         7QH(20),QHQFPL(20),QHQFMI(20),QHQAPL(20),QHQAMI(20),
 10.         8TOTPL(20),TOTMI(20),DIF(50),SLOIR(50),UNBAL(25),DLAIR(25)
 11.          ZLAM1=.450
 1     C
  .    C      RUDDER AND FAIR PLANE DESIGN CALCULATIONS
  :    C
              CALL STARTR
 16.          IF ACCUMULATOR OVERFLOW ,
```

```
      1    READ INPUT TAPE 1,2,(TITLE(I),I=1,24),AINIT,
          1AIFWD,AIAFT,AS1,AS2,CR,CT,SLOPCH,SPC,CS2,
          2CPL,BL,SPAN,Z1,Z2,CFL,CFU,SPWCPC,C1,C2,
          3SF1,SF2,GE,GE2,SLRT,RR,E,DLMULT,Z3,Z4,
          4SLO,DELXST,DIAMIN,EP1,EP2,CPSS,ARMS,SY,DD,DUD,
          5BETA,OMEGA,RHO,V,DR13PT
           SLIP=SLRT
      2    FORMAT(12A6/12A6/(5E13.7)          )
           READ INPUT TAPE 1,3133,STH,SPHD,PT
      3133 FORMAT(3E13.7                                        )
           V2=1.688*V*V*1.688
           XE=3.14159265*E
      C
      C    INITIALIZE
      C
           AT=AINIT
           AFWD=AIFWD
           AAFT=AIAFT
           BETAR=BETA*3.14159265/180.
           T=SIN (BETAR)/COS (BETAR)
           CRINIT=CR
           SPANIN=SPAN
           SLOIN=SLO
           SLOIR(1)=SLO
           L=1
           DLAIR(1)=DIAMIN
           CKS=.098175*(1.-DD**4)*SY
           DLA=DIAMIN
           CRLOOP=CR
           CM=(CT+CRLOOP)/2.
           XST(1)=CM*SLOIN
           TECL(1)=CM-XST(1)
           NL=1
           BPL=SPWCPC*SPAN+DR13PT
           ARMSIN=ARMS
           CPSSIN=CPSS
           DRPTIN=DR13PT
           READ INPUT TAPE 1,4,NDEL,NT,NT1,NFAP,NSS,NCN,N1R,
          1NDO,NX1,NX2,NX3,NX4
      4    FORMAT (6I4            )
           READ INPUT TAPE 1,3,(ADEL(M),M=1,NDEL)
           READ INPUT TAPE 1,3,(CLLOW(M),M=1,NDEL)
           READ INPUT TAPE 1,3,(CLHI(M),M=1,NDEL)
           READ INPUT TAPE 1,3,(CDLOW(M),M=1,NDEL)
           READ INPUT TAPE 1,3,(CDHI(M),M=1,NDEL)
           IF(NCN)3443,4334,3443
      3443 READ INPUT TAPE 1,3,(CNLOW(M),M=1,NDEL)
           READ INPUT TAPE 1,3,(CNHI(M),M=1,NDEL)
      4334 READ INPUT TAPE 1,3,(CPLOW(M),M=1,NDEL)
           READ INPUT TAPE 1,3,(CPHI(M),M=1,NDEL)
      3    FORMAT(6E13.7                    )
      C
      C
           DO 5 M=1,NDEL
```

```
      AA(M)=DLMULT*ADEL(M)
      AARAD(M)=AA(M)/180.*3.14159265
    5 SQRD(M)=AARAD(M)*AARAD(M)
C
C     WRITE OUT INPUT DATA AND TITLE
C
      WRITE OUTPUT TAPE 2,6,(TITLE(I),I=1,24)
    6 FORMAT(1H128X,12A6/29X,12A6/1H052X,
     124HTABULATION OF INPUT DATA          )
C
      WRITE OUTPUT TAPE 2,7,AIFWD,CR,AIAFT,CT,AINIT,SLOPCH
    7 FORMAT(1H018X,20HAREAS IN SQUARE FEET47X,14HCHORDS IN FEET//
     126X,18HINITIAL AREA FWD =F9.4,39X,14HINITIAL ROOT =F9.4/
     226X,18HINITIAL AREA AFT =F9.4,48X,5HTIP =F9.4/
     324X,20HINITIAL AREA TOTAL =F9.4,15X,
     438HSLOPED CHORD FOR CHANGING TOTAL AREA =F9.4                    )
      WRITE OUTPUT TAPE 2,8,SPAN,SPWCPC,DR13PT,DLMULT,BPL,
     1E,BL,RR,          CFL,CFU
C
    8 FORMAT(1H018X,15HLENGTHS IN FEET52X,
     121HDIMENSIONLESS NUMBERS//38X,6HSPAN =F9.4,28X,
     225HSPANWISE CP COEFFICIENT =F9.4/17X,
     327HROOT TO 1/3 POINT OF BRNG =F9.4,31X,
     422HMULTIPLIER TO GET AA =F9.4/26X,18HCP TO  NEAR BRNG =F9.4,
     531X,22HTAPER RATIO FACTOR E =F9.4/22X,22HLENGTH BETWEEN BRNGS =
     6F9.4,
     731X,26HFRACTION OF AREA IN RACE =F9.4/79X,
     827HBRNG FRICTION COEFF  NEAR =F9.4/79X,
     927HBRNG FRICTION COEFF OTHER =F9.4          )
      WRITE OUTPUT TAPE 2,600,CPSS,TECL(1),SPC
  600 FORMAT(1H014X,29HCENTER OF AREA TO NEAR BRNG =F9.4/5X,
     139HTRAILING EDGE TO CENTER LINE OF STOCK =F9.4/12X,
     232HSPAN FOR CHANGING BALANCE AREA =F9.4                        )
      WRITE OUTPUT TAPE 2,604,ARMS
  604 FORMAT(1H 18X,25HCENTER OF AREA TO STOCK =F9.4                 )
      WRITE OUTPUT TAPE 2,9,SF1,SF2,QE,QE2,DUD,DD,SLRT
    9 FORMAT(89X,17HSAFETY FACTOR 1 =F9.4/89X,
     117HSAFETY FACTOR 2 =F9.4/86X,20H+ ALLOWANCE FACTOR =F9.4/
     286X,20H- ALLOWANCE FACTOR =F9.4/83X,23HOTHER/ NEAR DIAMETERS =F
     3/83X,23HINNER/OUTER DIAMETERS =F9.4/ 94X,12HSLIP RATIO =F9.4
C
      WRITE OUTPUT TAPE 2,10,SY,BETA,RHO ,V ,SLO,
     1DELXST,NT
   10 FORMAT(1H018X,36HMISCELLANEOUS INPUT WITH DIMENSIONS        //
     119X,25HYIELD STRESS LB/SQ INCH =E12.4/21X,
     223HHULL SLOPE IN DEGREES =F9.4/18X,
     326HDENSITY LB SEC SQ/FT 4TH =F9.4/28X,
     416HVELOCITY KNOTS =F9.4/1H018X,
     525H(AS A RATIO)INITIAL SLO =F9.4/15X,
     629H(IN    FEET ) INITIAL DELXST =F9.4/1H011X,
     732HMAX NO. OF LOCATION ITERATIONS =I4/                  )
      WRITE OUTPUT TAPE 2,11,EP1,STH,SPHD
   11 FORMAT(1H020X,23HEPSILON FOR UNBALANCE =F9.4/16X,
     128HSLEEVE THICKNESS IN INCHES =F9.4,21X,
```

```
            227HSPHERICAL DIAMETER FACTOR =F9.4                    )
              IF(NFAP)624,625,624
        624   WRITE OUTPUT TAPE 2,626
        626   FORMAT(1H055X,19HTHE TIP IS FAIRED                          )
              GO TO 628
        625   WRITE OUTPUT TAPE 2,627
        627   FORMAT(1H055X,19HTHE TIP IS SQUARED                  )
        628   WRITE OUTPUT TAPE 2,7777,DIAMIN
       7777 FORMAT(1H041X,34HINITIAL STOCK DIAMETER IN INCHES =
            1E15.8                                                    )
      C
              WRITE OUTPUT TAPE 2,605
        605   FORMAT(1H155X,18HINPUT COEFFICIENTS               )
              WRITE OUTPUT TAPE 2,12,(ADEL(M),AA(M),CLLOW(M),CLHI(M),
             1CDLOW(M),CDHI(M),CNLOW(M),CNHI(M),CPLOW(M),CPHI(M),
             2M=1,NDEL)
         12   FORMAT(1H06X,4HADEL4X,22HATTACK ANGLE    CL LO
             152H        CL HI          CD LO          CD HI          CN LO
             239H  CN HI          CP LO          CP HI          /(1X,F11.4,1X,
             3F12.5,8F12.7))
      C
      C
      C       INTERPOLATION OR EXTRAPOLATION TO GET C1
      C
              READ INPUT TAPE 1,13,OMEGA1,OMEGA2
         13   FORMAT(2E13.7          )
              WRITE OUTPUT TAPE 2,14,OMEGA1,OMEGA2,OMEGA
         14   FORMAT(1H056X,10HLO ANGLE =F8.4/57X,10HHI ANGLE =F8.4//
             148X,26HSWEEP ANGLE OF 1/4 CHORD =F8.4                  )
              ODEL=OMEGA2-OMEGA1
              ODEL1=OMEGA-OMEGA1
              IF(NCN)608,609,608
        608   WRITE OUTPUT TAPE 2,607
        607   FORMAT(1H0///47X,36HTHE CN COEFFICIENTS ARE INTERPOLATED///
              GO TO 610
        609   WRITE OUTPUT TAPE 2,606
        606   FORMAT(1H0///49X,34HTHE CN COEFFICIENTS ARE CALCULATED///   )
        610   DO 15 M=1,NDEL
              CL1(M)=CLLOW(M)+(CLHI(M)-CLLOW(M))/ODEL*ODEL1
              CP1(M)=CPLOW(M)+(CPHI(M)-CPLOW(M))/ODEL*ODEL1
              CD1(M)=CDLOW(M)+(CDHI(M)-CDLOW(M))/ODEL*ODEL1
              IF(NCN)16,17,16
         17   CN1(M)=CL1(M)*COS (AARAD(M))+CD1(M)*SIN (AARAD(M))
              GO TO 1515
         16   CN1(M)=CNLOW(M)+(CNHI(M)-CNLOW(M))/ODEL*ODEL1
       1515   CR1(M)=SQRT (CD1(M)*CD1(M)+CL1(M)*CL1(M))
              CPC141(M)=.25-CP1(M)
              CMC141(M)=CN1(M)*CPC141(M)
         15   CONTINUE
      C
      C
              WRITE OUTPUT TAPE 2,18,(AA(M),CL1(M),CP1(M),CD1(M),CN1(M),
             1M=1,NDEL)
         18   FORMAT( 45X,35HINTERPOLATED VALUES OF COEFFICIENTS/1H0
```

```
               16X,12HATTACK ANGLE19X,3HCL123X,3HCP123X,3HCD123X,3HCN1/(1H0
576            210X,F5.2,4F26.4)          )
577              IF(NFAP)21,22,21
02          22   CDC1=.800
03               ZM=1.636363636
04               GO TO 23
05          21   CDC1=.4
06               ZM=.72727272
07          23   ZLAM2=CT/CRLOOP
10               B=CDC1-ZM*ZLAM1
11               CDC2=ZM*ZLAM2+B
12               DALA=AFWD/AT
13               GARE=SPAN/AT*SPAN
14               XCD=CDC2-CDC1
14      C
14      C        TAPER RATIO CORRECTION
14      C
15               IF(NSS)642,643,642
20         642   ARMS=0.0
21               CPSS=0.0
22         643   DO 24 M=1,NDEL
25               IF(N1R)611,612,611
30         611   ARE(M)=2.*GARE
31               GO TO 613
3          612   ARE(M)=GARE*(2.-AA(M)/25.)
           613   DELCL(M)=XCD*SCRD(M)/ARE(M)
34               CL2(M)=CL1(M)+DELCL(M)
35               SQCLS(M)=(CL2(M)+CL1(M))*DELCL(M)
36               DELCD(M)=SQCLS(M)/(XE*ARE(M))
37               CD2(M)=CD1(M)+DELCD(M)
40               CN2(M)=CL2(M)*COS (AARAD(M))+CD2(M)*SIN (AARAD(M))
40      C
40      C
40      C
40      C
41               CMC142(M)=CMC141(M)-.5*DELCL(M)
42               CPC142(M)=CMC142(M)/CN2(M)
43               CPLE2(M)=.25-CPC142(M)
44          24   CR2(M)=SQRT (CL2(M)*CL2(M)+CD2(M)*CD2(M))
46          60   SQ=AT*V2*(RR*(1.+SLIP)**2+1.-RR)/2.*RHO
47               BBM=0.0
50               DO 29 M=1,NDEL
53               FN(M)=CN2(M)*SQ
54               FR(M)=CR2(M)*SQ
55               BM(M)=FR(M)*BPL*12.
56               IF(ABS (BM(M))-BBM)29,29,28
61          28   BBM=ABS (BM(M))
62          29   CONTINUE
64               WRITE OUTPUT TAPE 2,2323,L,AT,AFWD, DLA,SPAN,
6               1SLO,CRLOOP
          2323 FORMAT(1H1/////1H049X,25HTHIS IS ITERATION NUMBER I4//
             1   15X,12HTOTAL AREA =E15.8,3X,14HAREA FORWARD =E15.8,3X,
75           214H    DIAMETER =E15.8//1H024X,6HSPAN =E15.8,8X,
75           35HSLO =E15.8,8X,4HCR =E15.8                          )
```

```
      WRITE OUTPUT TAPE 2,640,CPSS,ARMS
  640 FORMAT(1H051X,29HCENTER OF AREA TO NEAR BRNG =E15.8//1H052X,
     128HCENTER OF AREA TO STOCK CL =E15.8                           )
      WRITE OUTPUT TAPE 2,614,TECL(L)
  614 FORMAT(1H043X,24HTRAILING EDGE TO STOCK =E13.6,
     16H  FEET                                  )
      WRITE OUTPUT TAPE 2,641,DR13PT,BPL
  641 FORMAT(1H040X,25HROOT TO 1/3 PT. OF BRNG =E15.8//49X,
     117HCP TO NEAR BRNG =E15.8                               )
      WRITE OUTPUT TAPE 2,25,ZLAM1,ZLAM2,CDC1,CDC2,NFAP
   25 FORMAT(1H153X,22HTAPER RATIO CORRECTION/1H03X,
     19HLAMBDA1 =F10.5,8X,9HLAMBDA2 =F10.5,8X,6HCDC1 =F10.5,10X,
     26HCDC2 =F10.5,13X,6HNFAP =I4                        )
      WRITE OUTPUT TAPE 2,26,(AA(M),AARAD(M),GARE,ARE(M),
     1DELCL(M),CL2(M),DELCD(M),CD2(M),M=1,NDEL)
   26 FORMAT(1H01X,32H  ATTACK ANGLE      IN RADIANS
     148H   GEOMETRIC        ASPECT RATIO        DELCL
     248H       CL2             DELCD             CD2         /
     3(1H0F12.2,F18.6,F14.4,F17.4,F15.5,F17.5,F15.5,F17.5         )
      WRITE OUTPUT TAPE 2,27,(AA(M),AARAD(M),CN2(M),CMC142(M),
     1CPC142(M),CPLE2(M),CR1(M),CR2(M),M=1,NDEL)
   27 FORMAT(1H01X,32H  ATTACK ANGLE      IN RADIANS
     148H       CN2             CMC142            CPC142
     248H     CPLE2             CR1               CR2         /
     3(1H0F12.2,F18.6,F14.4,F17.4,F15.5,F17.5,F15.5,F17.5         )
C
C     CALCULATIONS OF TORQUES TO GET UNBALANCE
C
C
C     FRICTION TORQUE CALCULATIONS
C
      DO 35 M=1,NDEL
      IF(CFU)135,136,135
  136 FL(M)=FR(M)
      FU(M)=FR(M)
      GO TO 137
  135 FL(M)=FR(M)*(BPL+BL)/BL
      FU(M)=FR(M)/BL*BPL
  137 CK15(M)=CFL*FL(M)*.5
      CK16(M)=CFU/2.*FU(M)
      IF(CFL-.1)30,31,31
   30 Q1(M)=CK15(M)*SPHD*DLA
      GO TO 32
   31 Q1(M)=CK15(M)*(DLA+2.*STH)
   32 IF(CFU-.1)33,34,34
   33 Q2(M)=CK16(M)*SPHD*DLA*DUD
      GO TO 35
   34 Q2(M)=CK16(M)*DLA*DUD
C
C
   35 QF(M)=Q1(M)+Q2(M)
      WRITE OUTPUT TAPE2,36,SQ,(FN(M),FR(M),FL(M),
     1FU(M),M=1,NDEL)
   36 FORMAT(1H145X,32HTABLES OF FORCES AND TORQUES ON
```

```
           16HRUDDER/14HOCONSTANT SQ =E13.6,26H       NORMAL FORCE
           252H       RESULTANT FORCE         FORCE ON  NEAR BRNG.
           326H   FORCE ON OTHER BRNG.    //(1H031X,E15.8,12X,E15.8,10X,
           4E15.8,11X,E15.8              )             )
      C
      C
            WRITE OUTPUT TAPE 2,37,(AA(M),CK15(M),CK16(M),Q1(M),
           1Q2(M),QF(M),M=1,NDEL)
   37       FORMAT(1H04X,12HATTACK ANGLE14X,4HCK1518X,4HCK1619X,
           12HQ120X,2HQ220X,2HQF/(1H05X,F7.3,5X,5E22.6)         )
      C
      C     CALCULATION OF QA PLUS AND QA MINUS
      C
            DO 38 M=1,NDEL
            QAPL(M)=QE*CM*FN(M)*12.
   38       QAMI (M)=QE2*CM*FN(M)*12.
      C
      C     CALCULATIONS OF QH AND FINAL CALCULATIONS
      C
            BTOTPL=0.0
            BTOTMI=0.0
            DO 42 M=1,NDEL
            QH(M)=  (SLC -   CPLE2(M))*CM*FN(M)*12.
            QHQFPL(M)=QH(M)+QF(M)
            QHQFMI(M)=QH(M)-QF(M)
            QHQAPL(M)=QH(M)+QAPL(M)
            QHQAMI(M)=QH(M)-QAMI(M)
            TOTPL(M)=QHQFPL(M)+QAPL(M)
            IF(ABS (TOTPL(M))-BTOTPL)40,40,39
   39       BTOTPL=ABS (TOTPL(M))
      C
   40       TOTMI(M)=QHQFMI(M)-QAMI(M)
            IF(ABS (TOTMI(M))-BTOTMI)42,42,41
   41       BTOTMI=ABS (TOTMI(M))
   42       CONTINUE
   62       DIF(L)=BTOTPL-BTOTMI
            SFS=12000.*AT
            BMSS=SFS*CPSS
            QSS=SFS*ARMS
  620       UBM=BBM
            B1=UBM*UBM
   57       IF(DIF(L))59,59,58
      C
      C
   58       DLA=((UBM+SQRT (B1+BTOTPL*BTOTPL))/(2.*CK5)*SF1
           1)**.33333333
            GO TO 56
   59       DLA=((UBM+SQRT (B1+BTOTMI*BTOTMI))/(2.*CK5)*SF1
           1)**.33333333
      C     56 CONTAINS A CALCULATION FOR DLA CONSIDERING
      C     SEA SLAP FORCE
   56       DL =((UBM +SQRT (B1       +QSS*QSS))/(2.*CK5)*
           1SF2)**.33333333
            IF(DLA-DL)622,622,2423
```

```
  622 DLA=DL
C
C
C
C
 2423 WRITE OUTPUT TAPE 2,2324,L,AT,AFWD,BALA,SPAN,
     1SLO,CRLOOP,CM,DLA,BBM
 2324 FORMAT(1H148X,25HTHIS WAS ITERATION NUMBER I4//16X,
     112HTOTAL AREA =E15.8,3X,14HAREA FORWARD =E15.8,3X,
     214HAREA BALANCE =E15.8//  17X,6HSPAN =E15.8,8X,
     35HSLO =E15.8,8X,12HROOT CHORD =E15.8//17X,
     412HMEAN CHORD =E15.8,4X,16HSTOCK DIAMETER =E15.8,4X,
     516HBENDING MOMENT =E15.8                    )
      WRITE OUTPUT TAPE 2,645,BMSS,OSS
  645 FORMAT(1H049X,25HSEA SLAP BENDING MOMENT =E15.8//58X,
     117HSEA SLAP TORQUE =E15.8                        )
      WRITE OUTPUT TAPE 2,43,(AA(M),FN(M),QH(M),QAPL(M),QAMI(M),
     1QHQAPL(M),QHQAMI(M),M=1,NDEL)
   43 FORMAT(1H031X,33HTABLE OF HYDRODYNAMIC TORQUE AND
     132HALLOWANCE TORQUE WITH THEIR SUMS/    6X,
     212HATTACK ANGLE6X,12HNORMAL FORCE11X,2HQH15X,3H+QA15X,3H-QA13X,
     37HQH + QA11X,
     47HQH - QA//(9X,F5.2,6X,6E18.8                 )  //          )
      WRITE OUTPUTTAPE2,44,(ADEL(M),AA(M),QF(M),QHQFPL(M),QHQFMI(M),
     1TOTPL(M),TOTMI(M),M=1,NDEL)
C
   44 FORMAT(1H046X,36HTABLE OF TOTAL TORQUE PLUS AND MINUS/
     1    4X,16HDEFLECTION ANGLE4X,12HATTACK ANGLE10X,2HQF13X,7HQH + QF
     211X,7HQH - QF9X,
     312HQH + QF + QA 6X,12HQH - QF - QA//(9X,F5.2,6X,6E18.8//  )  )
      IF(NT-1)470,470,46
   46 IF(ABS (DIF(L))-EP1)47,47,48
   48 IF(L-1)49,49,50
   49 IF(DIF(L))51,52,52
   52 DELXST=-DELXST
   51 FALPO=XST(1)+DELXST
      GO TO 53
   50 IF(NT-L)54,54,55
   55 FALPO=(DIF(L-1)*XST(L)-DIF(L)*XST(L-1))/
     1(DIF(L-1)-DIF(L))
   53 L=L+1
      NL=L
      XST(L)=FALPO
      DELXST=XST(1)-XST(L)
      ARMS=ARMSIN+DELXST
      DELS=DELXST*T
      DRISPT=DRPTIN-DELS
      CPSS=CPSSIN+DELS
      SPAN=SPANIN +DELS
      CRLOOP=(CRINIT-CT)*SPAN/SPANIN+CT
      CM=(CT+CRLOOP)/2.
      TECL(L)=CM-XST(L)
      SLO=XST(L)/CM
      SLOIR(L)=SLO
```

```
              DELTH=DELXST*SIN (BETAR)
              DELTA=DELTH*SLOPCH
              AT=AINIT+DELTA
              DELAFW=DELXST*(DELTH-SPC)
              AFWD=AIFWD+DELAFW
              BPL=SPWCPC*SPAN+DR13PT
              DLAIR(L)=DLA
              GO TO 23
      C
      C
      C
      C
         47   WRITE OUTPUT TAPE 2,4747,SLO,DLA,CM,CRLOOP,(SLOIR(I),
             1DLAIR(I),DIF(I),I=1,NL)
         4747 FORMAT(1H155X,21HTHE FINAL ANSWERS ARE///51X,
             116HSTOCK LOCATION =E15.8///51X,16HSTOCK DIAMETER =E15.8///
             2 55X,12HMEAN CHORD =E15.8///55X,12HROOT CHORD =E15.8/1H014X,
             315HSTOCK LOCATIONS25X,15HSTOCK DIAMETERS25X,10HUNBALANCES//
             4(19X,E15.8,25X,E15.8,22X,E15.8         )              )
              WRITE OUTPUT TAPE 2,7222,(XST(I),I=1,NL  )
         7222 FORMAT(1H033X,40HDISTANCE FROM  LEADING EDGE TO STOCK ON
             117HMEAN CHORD (FEET)/(65X,E15.8                  )        )
              WRITE OUTPUT TAPE 2,630,(TECL(I),I=1,NL)
         630  FORMAT(1H033X,40HDISTANCE FROM TRAILING EDGE TO STOCK ON
             117HMEAN CHORD (FEET)/(65X,E15.8                  )        )
         70   XNX=1.
              DELXST=XST(L)-XST(1)
         722  IF(ABS (DELXST)-XNX*PT)71,71,72
         72   XNX=XNX+1.
              GO TO 722
         71   IF(DELXST)73,73,74
         73   FALPO=XST(1)-XNX*PT
              NT=1
              GO TO 53
         74   FALPO=XST(1)+XNX*PT
              NT=1
              GO TO 53
         470  PT=12.*PT
              XST(L)=12.*XST(L)
              TECL(L)=12.*TECL(L)
              WRITE OUTPUT TAPE 2,4070,PT,SLO,CM,CRLOOP,
             1DLA,XST(L),TECL(L)
         4070 FORMAT(1H150X,13HTHE ANSWER TOF7.4,8H  INCHES///
             148X,16HSTOCK LOCATION =E15.8//45X,19HMEAN CHORD (FEET) =E15.8//
             245X,19HROOT CHORD (FEET) =E15.8//39X,23HSTOCK DIAMETER (INCHES)
             32H =E15.8//4X,41HDISTANCE (ON MEAN CHORD) LEADING EDGE TO
             419HSTOCK CL (INCHES) =E15.8//3X,25HDISTANCE (ON MEAN CHORD)
             536HTRAILING EDGE TO STOCK CL (INCHES) =E15.8                 )
              GO TO 1
         54   WRITE OUTPUT TAPE 2,5454,AT,SPAN,CRLOOP,(SLOIR(I),DIF(I),
             1I=1,NT)
         5454 FORMAT(1H138X,32HERROR RETURN  NO CONVERGENCE ON
             122HLOCATION    NT EXCEEDED/1H029X,
             212HTOTAL AREA =E15.8,2X,6HSPAN =E15.8,2X,4HCR =E15.8/
```

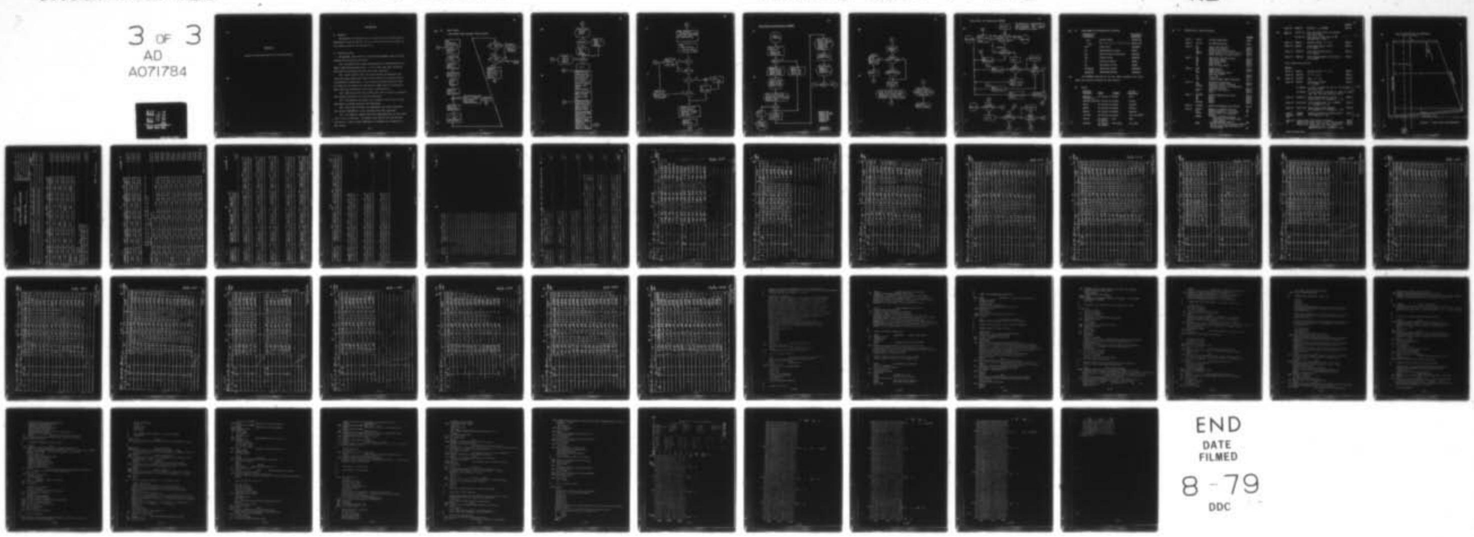
1454 HRS. APR 11, 1967 TAG ROOM 210

```
 1347    449.       31H026X,15HSTOCK LOCATIONS30X,9HUNBALANCE/(1H026X,
01347    450.       4E15.8,27X,E15.8                          )
01350    451.        GO TO 1
01351    452.        END
```

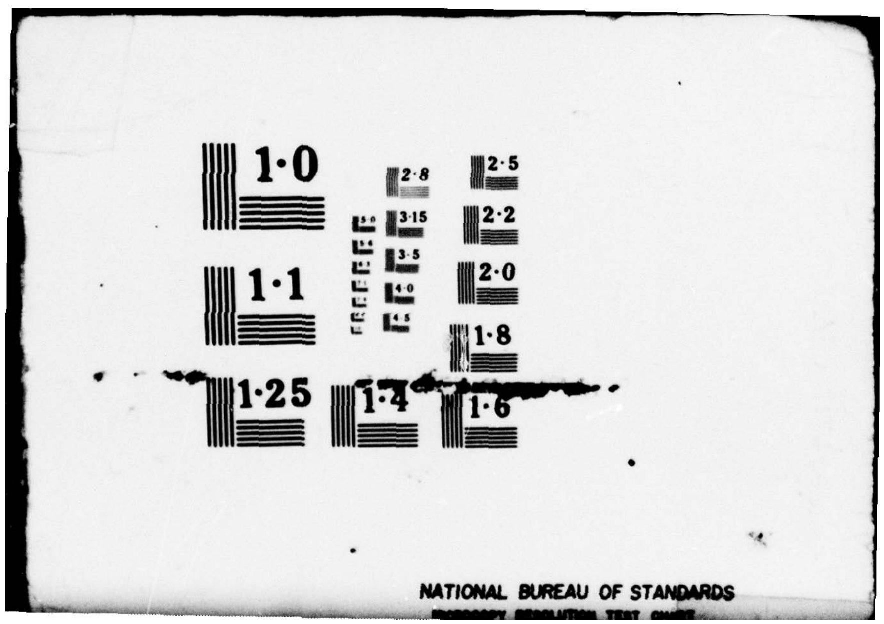
END OF LISTING.   1 *DIAGNOSTIC* MESSAGE(S).

AD-A071 784 ROSENBLATT (M) AND SON INC NEW YORK F/G 13/10
DEVELOPMENT OF A TECHNICAL PRACTICE FOR RUDDERS AND DIVING PLAN--ETC(U)
AUG 74 R SHEFFIELD N00024-73-C-5189
UNCLASSIFIED MR/S-2499-3 NAVSEC-6136-74-272 NL

3 OF 3
AD
A071784



END
DATE
FILMED
8-79
DDC


1·0
2·8
2·5
3·15
2·2
3·5
1·1
2·0
4·0
4·5
1·8
1·25
1·4
1·6
NATIONAL BUREAU OF STANDARDS

APPENDIX H

Computer Program Documentation for Stern Plane Design

I

DESCRIPTION

A. Purpose

The purpose of the program is to give the Naval Architecture Department a tool by which they can obtain stern plane designs in the minimum time at the minimum cost.

B. General Method

In general, the method of finding the optimum stock location follows the following procedure:

(1) An initial geometric configuration is determined by the Naval Architecture Department. At the same time they determine the speed of the ship and other physical constants.

(2) Given initial lift and hinge moment coefficients (or lists of hinge moment and lift coefficients) the program arrives at corrected coefficients. The corrected coefficients may also be "read in" in which case the program skips over the correction phase and just determines the torques and unbalance.

(3) With the corrected coefficients and the initial geometry the program determines an initial unbalance.

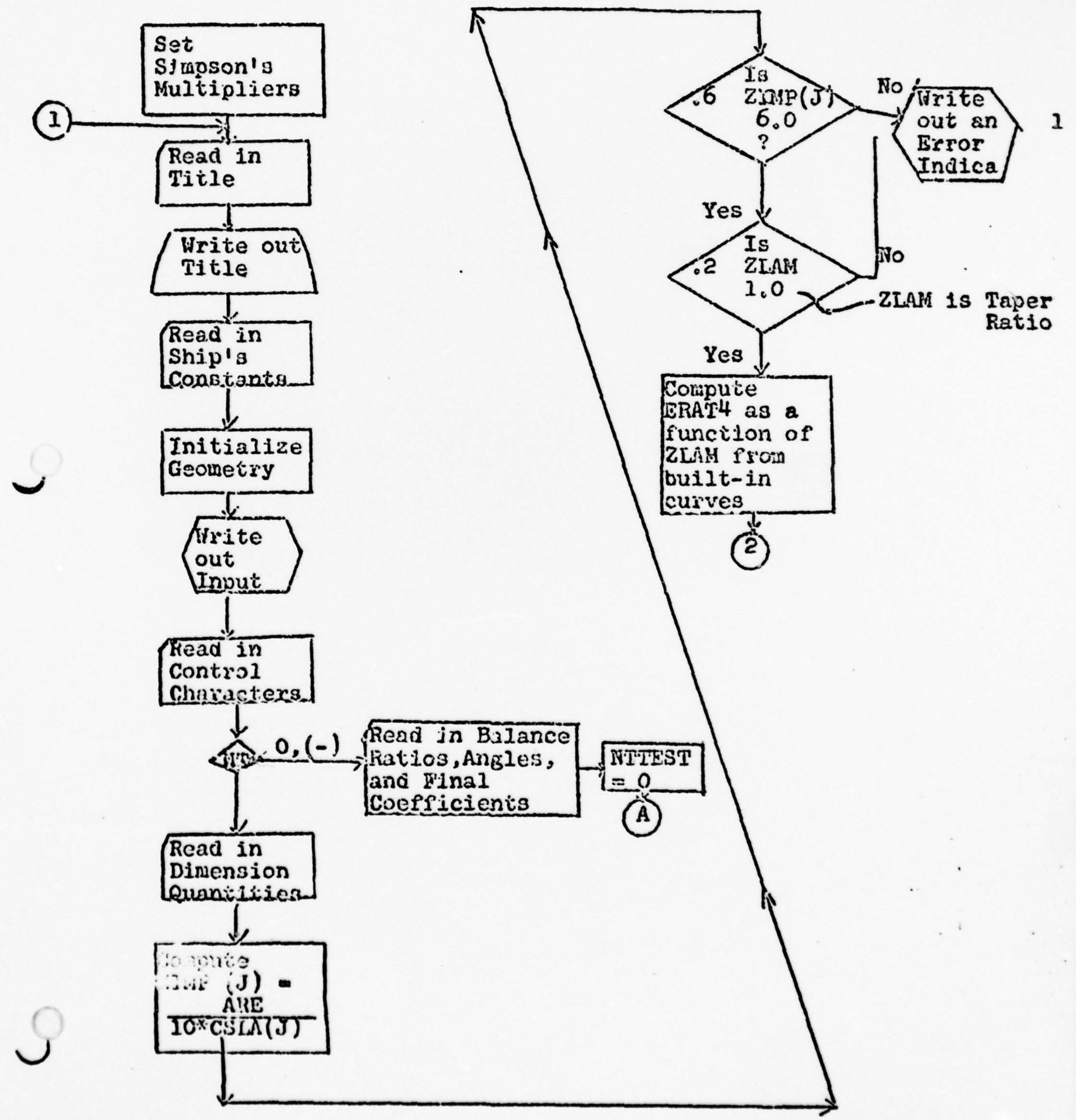
(4) The program increments the original stock location and determines a second geometry and unbalance.

(5) Using the previous two unbalances and stock locations the program determines a new geometry and stock location.

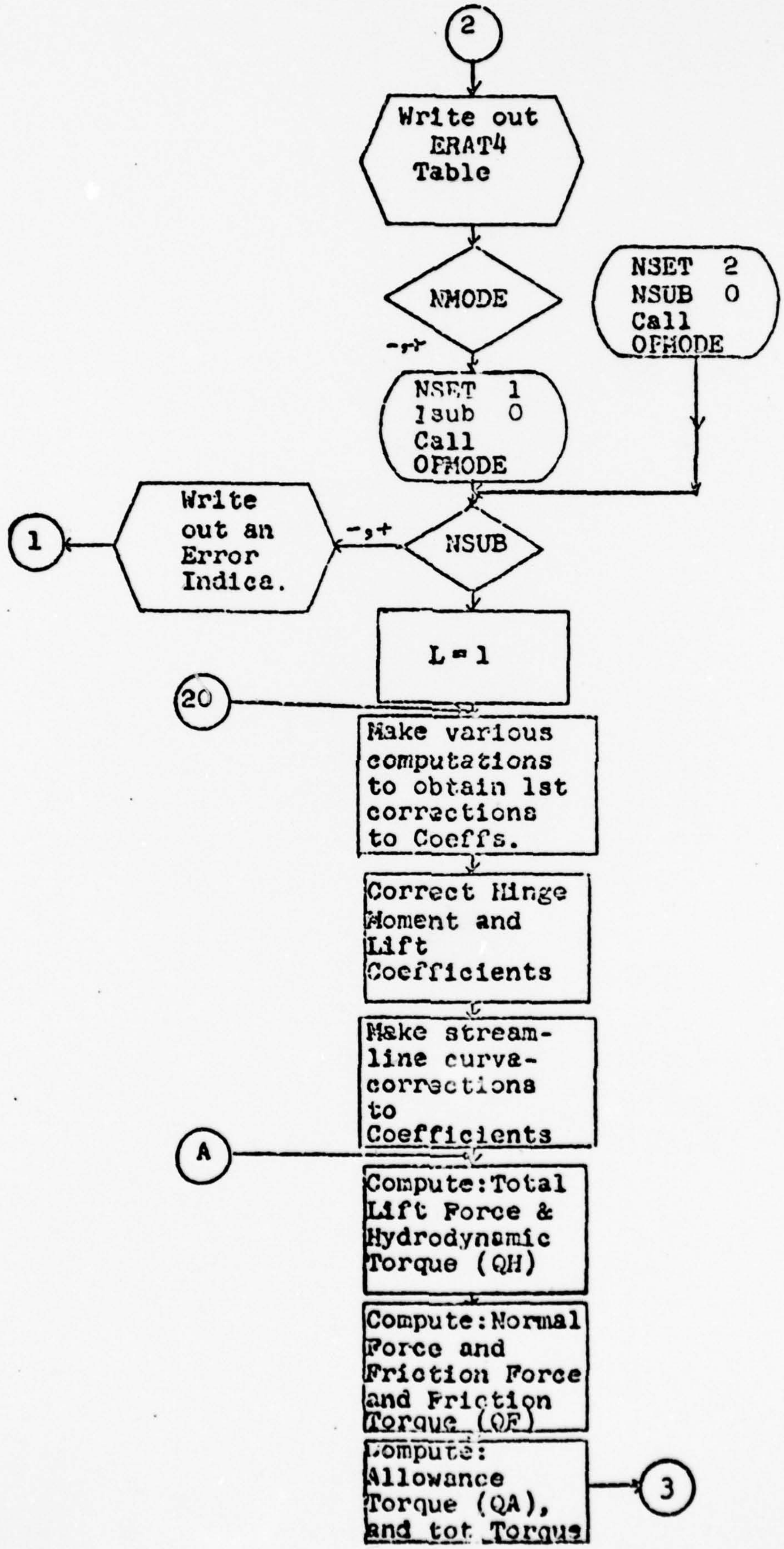
(6) The program repeats (5) until the unbalance is less then some "read in" epsilon. If during steps (3) or (4) the program arrives at a small enough unbalance it accepts that geometry as the answer.

F. Flow Charts

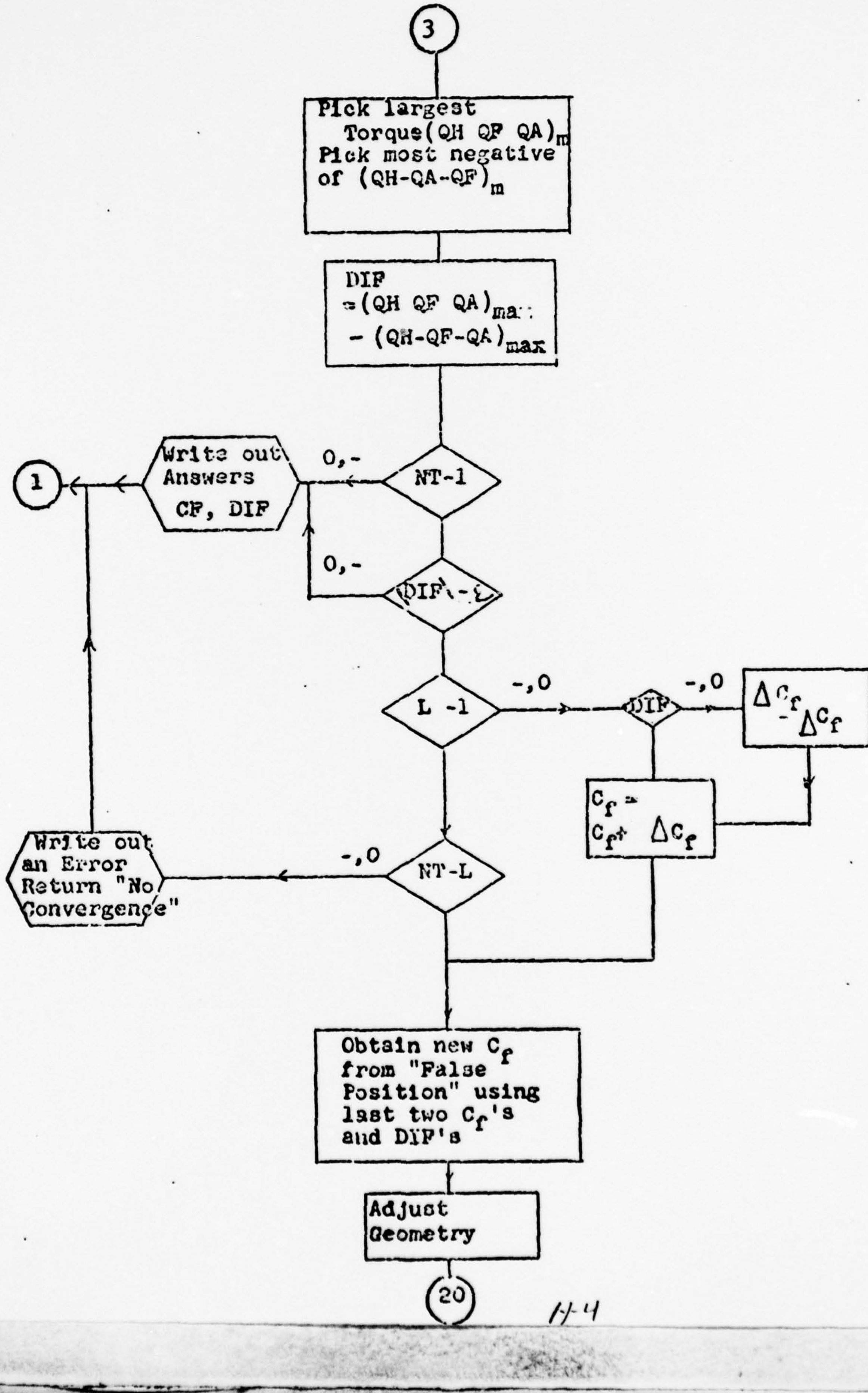
Flow Chart main program "Stern Plane"



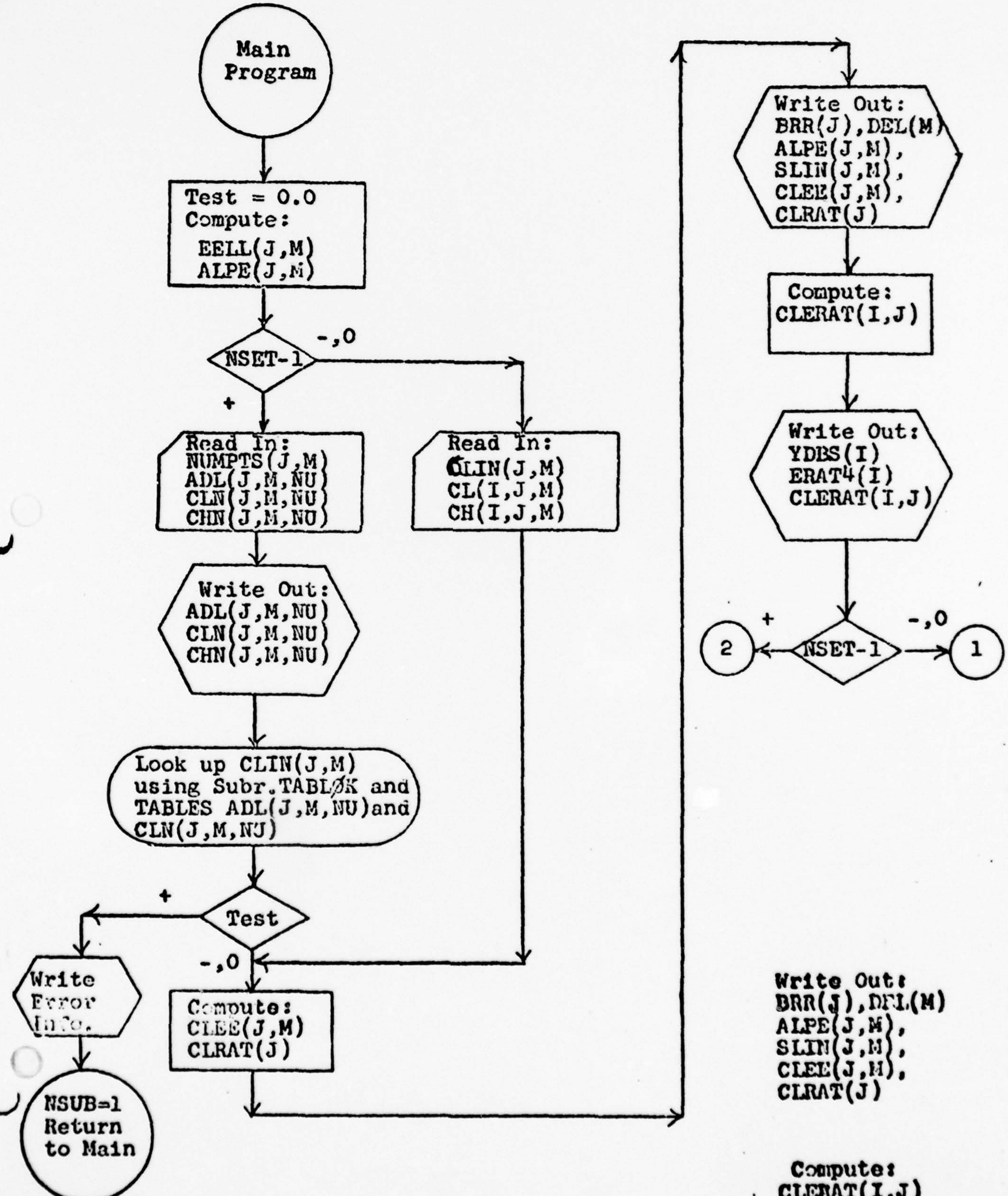
H 2


2
Write out ERAT4 Table
NMODE
-,+
NSET 2
NSUB 0
Call OPMODE
NSET 1
Isub 0
Call OPMODE
NSUB
-,+
Write out an Error Indica.
1
L = 1
20
Make various computations to obtain 1st corrections to Coeffs.
Correct Hinge Moment and Lift Coefficients
Make stream-line curva-corrections to Coefficients
A
Compute: Total Lift Force & Hydrodynamic Torque (QH)
Compute: Normal Force and Friction Force and Friction Torque (QF)
Compute: Allowance Torque (QA), and tot Torque
3

H3


3
Pick largest Torque(QH QF QA)m
Pick most negative of (QH-QA-QF)m
DIF =(QH QF QA)max - (QH-QF-QA)max
NT-1
0,-
Write out Answers CF, DIF
1
0,-
DIF - ε
L -1
-,0
DIF
-,0
ΔCf = -ΔCf
Cf = Cf + ΔCf
-,0
NT-L
Write out an Error Return "No Convergence"
Obtain new Cf from "False Position" using last two Cf's and DIF's
Adjust Geometry
20

Flow Chart for Subroutine OPMODE



Write Out:
BRR(J),DEL(M)
ALPE(J,M),
SLIN(J,M),
CLEE(J,M),
CLRAT(J)

Compute:
CLERAT(I,J)

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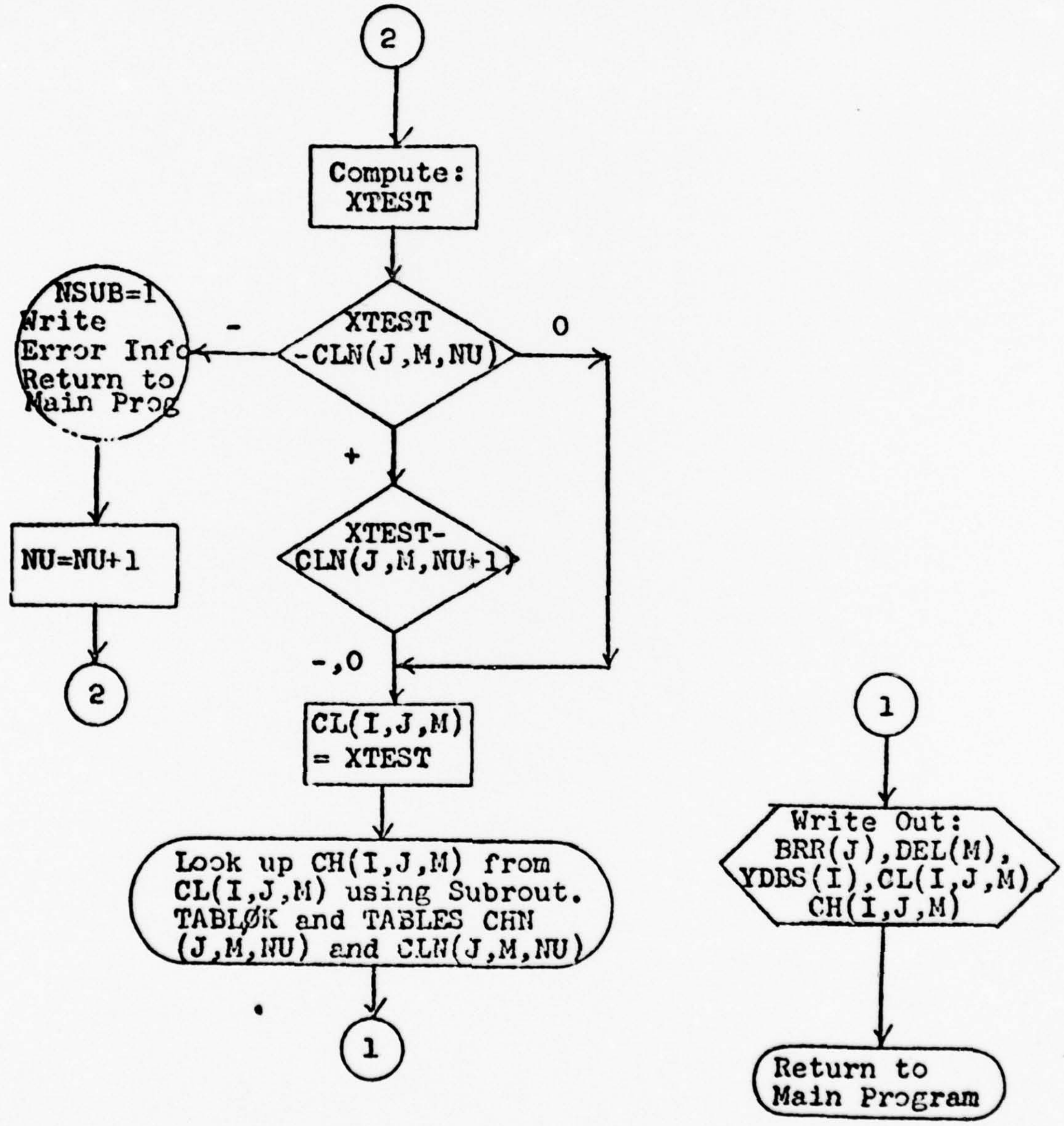
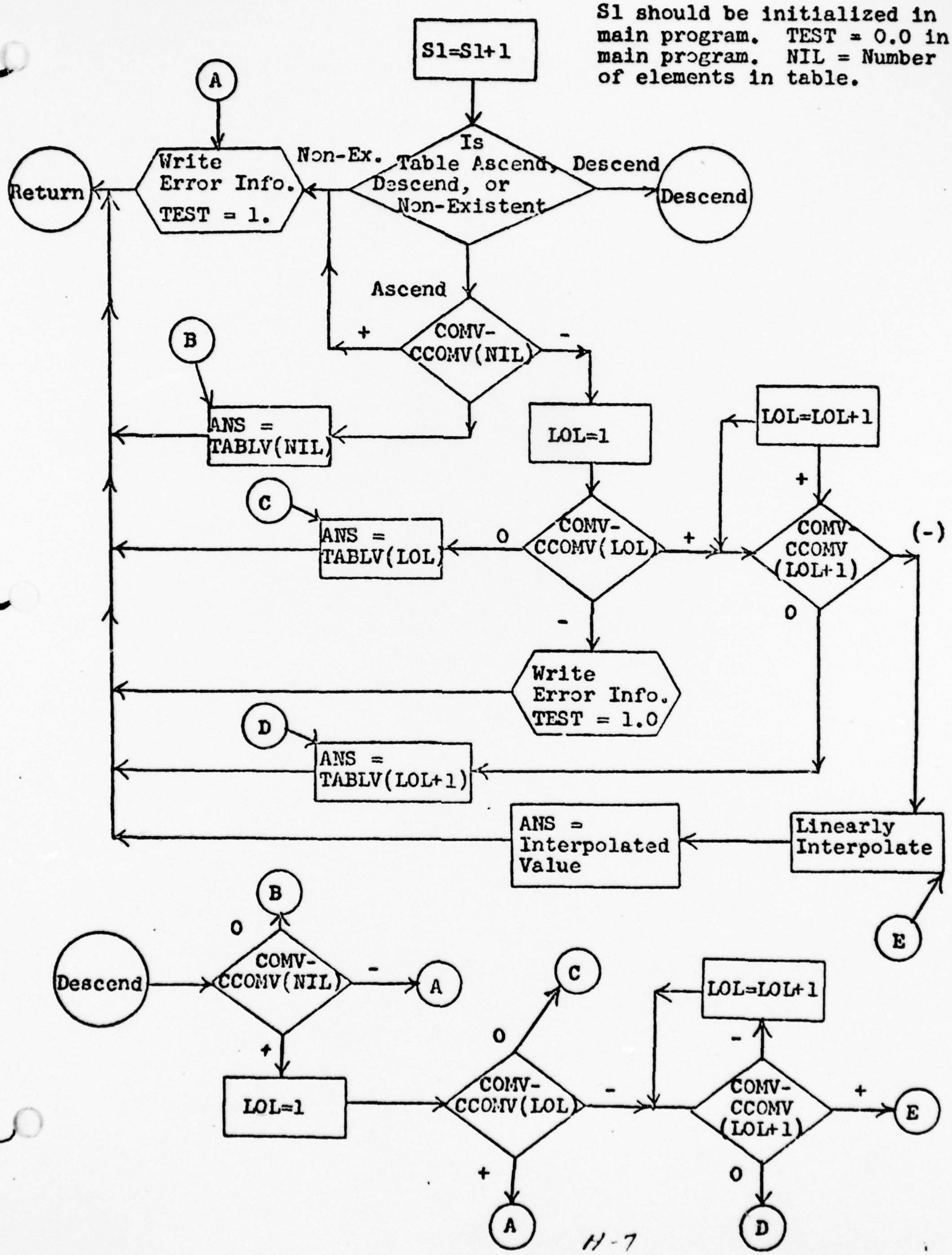

2
Compute:
XTEST
XTEST
-CLN(J,M,NU)
-
0
+
NSUB=1
Write
Error Info
Return to
Main Prog
NU=NU+1
2
XTEST-
CLN(J,M,NU+1)
-,0
CL(I,J,M)
= XTEST
Look up CH(I,J,M) from
CL(I,J,M) using Subrout.
TABLØK and TABLES CHN
(J,M,NU) and CLN(J,M,NU)
1
1
Write Out:
BRR(J),DEL(M),
YDBS(I),CL(I,J,M),
CH(I,J,M)
Return to
Main Program

Flow Chart for Subroutine TABLØK

S1 should be initialized in main program. TEST = 0.0 in main program. NIL = Number of elements in table.



H-7

G. Programmed and Mathematical Notation

Mathematical Notation		Programmed Notation
α_e	Attack Angle	ALPE(J,M)
ϵ_{ell}	Downwash Angle for Elliptical Loading	EELL(J,M)
Lift	Total Lift	ZLIFT(M)
Q_H	Hydrodynamic Torque	QH(M)
C_{nf}	Normal Force Coefficient	CNFC(M)
F_{nf}	Normal Force	FNFC(M)
Q_f	Friction Torque	QF(M)
Q_A	Allowance Torque	QA(M)
$Q_f+Q_H+Q_A$	Upsetting Moment	CMOMU(M)
$Q_H-Q_A-Q_f$	Restoring Moment	CMOMR(M)

The FORTRAN expressions for the other variables are found where the variable appears in this report.

H. Units

Physical Quantity	Input	Output	During Execution
Lengths (Geometric)	As listed on Output		Feet
Lengths (Arms)	As listed on Output		Inches
Areas	As listed on Output		$(\text{Feet})^2$
Speed	As listed on Output		Ft/sec.
Angles	As listed on Output		Degrees
Density	As listed on Output		$\text{Lb.-sec.}^2/\text{Ft}^4$
Forces	As listed on Output	Lbs.	Lbs.
Torques	As listed on Output	Lbs.-inch	Lb.-inch

I. Definition of Data Variables

			Format
Card 1	Title	72 BCD Characters	12A6
Card 2	Title	72 BCD Characters	12A6
Card 3	AP	Plane Area (Sq.Ft)	E13.7
	AT	Total Area (Sq.Ft)	E13.7
	AF	Initial Flap Area (Sq.Ft)	E13.7
	OMEGA	Sweep Angle of 1/4 Chord (Deg.)	E13.7
	CB	Chord Forward of Stock (Feet)	E13.7
Card 4	CF	Chord Aft of Stock (Feet)	E13.7
	CT	Tip Chord (Feet)	E13.7
	CR	Root Chord (Feet)	E13.7
	S	Span (Feet)	E13.7
	SF	Span of Flap (Feet)	E13.7
Card 5	ARE	Aspect Ratio	E13.7
	V	Speed (Knots)	E13.7
	RHO	Density of Salt Water (Lb.-sec.^{2}/Ft^4)	E13.7
	ZK	$1-C_{L\alpha}/C_{l\alpha}$	E13.7
	PHI	Trailing Edge Angle (Degrees)	E13.7
Card 6	AU	Friction Coefficient	E13.7
	RAD	Weighted Radious (Inches)	E13.7
	ALOFAC	Allowance Factor for Computing Allowance Torque	E13.7
	CFINC	Initial ΔCF (Feet)	E13.7
	ZT	Spare	E13.7
Card 7	EPSLON	Balance Epsilon (Lb.-In.)	E13.7
	S1	Spare	E13.7
	S2	Spare	E13.7
	S3	Spare	E13.7
	ASPARE	Spare	E13.7
Card 8	SPFCHA	Span for Changing Area (Feet)	E13.7
Card 9	NYDES	Number of Y/(b/2) Stations	I5
	NT	Maximum Number of Iterations	I5
	NDEL1	Total Number of Deflection Angles	I5
	NMODE	= 0 Lift and Hinge Moment Coefficients obtained from Input Points = 1 Coefficients Read In	I5
	NDEL	Number of Deflection Angles Uused to get first Approximation to Coefficients	I5

			Format
Card 10	YDBS(I)	Y/(b/2) I = 1,NYDBS	5E13.7
NT = 0	If NT = 0	fill in cards 11-14, 14 becomes last data card	
	If NT ≠ 0	omit cards 11-14, fill in 15 through end of data	
Card 11	BRR(J)	Balance Ratios J = 1,3	3E13.7
Card 12	DEL(M)	Deflection Angles (deg.) M = 1,NDEL1	5E13.7
Card 13	CLBL(M)	Final Lift Coefficients M = 1,NDEL1	5E13.7
Card 14	CHBL(M)	Final Hinge Moment Coefficients M = 1,NDEL1	5E13.7

Go to Final Calculations

NT ≠ 0			
Card 15	BRR(J)	Balance Ratios J = 1,3	3E13.7
Card 16	ADEL(J)	$\alpha\delta$ J = 1,3	3E13.7
Card 17	CSLA(J)	C_{ℓ_α} J = 1,3	3E13.7
Card 18	DEL(M)	Deflection Angles M = 1,NDEL1	5E13.7
	If NMODE = 1, fill in cards 19, 20, 21 - 21 becomes last data card		
	If NMODE = 0, omit cards 19 through 21, fill in cards 22A, 22B, 22C and cards in set 23		
Card 19	CLIN(J,M)	First Approximation to Lift Coefficients M = 1,NDEL; J = 1,3	4E13.7
Card 20	CL(I,J,M)	Lift Coefficients M = 1,NDEL1; I = 1,NYDBS; J = 1,3	6E13.7
Card 21	CH(I,J,M)	Hinge Moment Coefficients M = 1,NDEL1; I = 1,NYDBS; J = 1,3	6E13.7
Cards 22A,22B 22C	NUMPTS (J,M)	Number of Points on Input Curves M = 1,NDEL; J = 1,3	10I5
Card Set 23	ADL(J,M,NU)	Input Table of Alphas	F10.6
	CLN(J,M,NU)	Input Table of Lift Coefficients	F10.6
	CHN(J,M,NU)	Input Table of Hinge Moment Coefficients NU = 1; (NPTS = NUMPTS(J,M)); M = 1,NDEL; J = 1,3	F10.6

End of Input Data

H 10

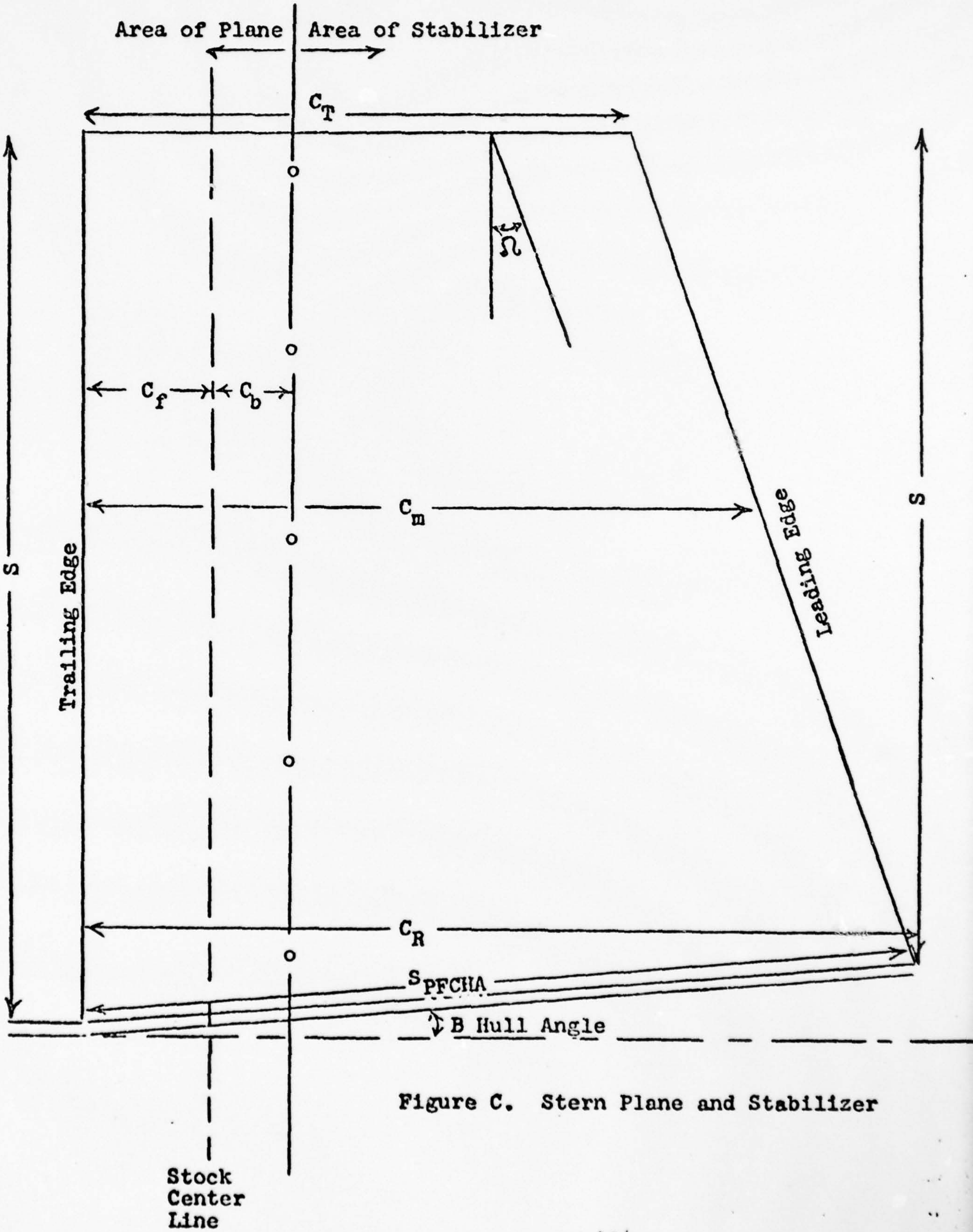


Figure C. Stern Plane and Stabilizer

UNIVAC 1107 PROGRAM 0218

GD/EB

STERN PLANE TØRQUE CALCULATIØNS

ESTIMATED RUN TIME ____________

Log No. ____________
Customer ____________
Phone ____________
S.O. ____________
DWO ____________
Return To ____________

(Cards 1 & 2 must be present. even if blank--omit other cards when blank in Cols 1-72)

Card number

COL 1 Title Line 1 72 Alphanumeric Characters 72 78 79 80

	Card
	1

COL 1 Title Line 2 72 Alphanumeric Characters

	Card
	2

COL 1

AP (1–13)	AT (14–26)	AF (27–39)	OMEGA (40–52)	CB (53–65)	Card
±.xxxxxxxE±xx	±.xxxxxxxE±xx	±.xxxxxxxE±xx	±.xxxxxxxE±xx	±.xxxxxxxE±xx	3
CF	CT	CR	S	SF	4
ARE	V	RHO	ZK	PHI	5
AU	RAD	ALØFAC	CFINC	ZT	6
EPSILON	SY	S2	S3	ASPARE	7
SFCHA					8

NOBS (5)	NT (10)	NDELI (15)	NMODE (20)	NDEL (25)	IDUMP (30)	Card
xxxx	xxxxx	xxxxx	xxxxx	xxxxx	xxxxx	0

Page 1 of ________

H 12

YDBS(1) 13	(2) 26	(3) 39	(4) 52	(5) 65	Card
±.XXXXXXXE±XX	±.XXXXXXXE±XX	±.XXXXXXXE±XX	±.XXXXXXXE±XX	±.XXXXXXXE±XX	10 A
(6)	(7)	(8)	(9)	(10)	10 B
(11)	(12)	(13)	(14)	(15)	10 C

IF NT = 0 fill in cards 11 through 14, 14 becomes last input card
IF NT ≠ 0 fill in cards 15 through end of data

					Card
BRR (1)	BRR (2)	BRR (3)			11
DEL (1)	(2)	(3)	(4)	(5)	12 A
(6)	(7)	(8)	(9)	(10)	12 B
(11)	(12)	(13)	(14)	(15)	12 C
CLBL (1)	(2)	(3)	(4)	(5)	13 A
(6)	(7)	(8)	(9)	(10)	13 B
(11)	(12)	(13)	(14)	(15)	13 C
CHBL (1)	(2)	(3)	(4)	(5)	14 A
(6)	(7)	(8)	(9)	(10)	14 B
(11)	(12)	(13)	(14)	(15)	14 C

1	13	26	39	52
CLIN(J,M)	CLIN(J,M)	CLIN(J,M)	CLIN(J,M)	
X.XXXXXXXE±	XXXXXXXE±XX	X.XXXXXXXE±XX	X.XXXXXXXE±XX	
. E	. E	. E	. E	

80: 19

1	13	26	39	52	65	78
CL(I,J,M)	CL(I,J,M)	CL(I,J,M)	CL(I,J,M)	CL(I,J,M)	CL(I,J,M)	
X.XXXXXXXE±XX	X.XXXXXXXE±XX	X.XXXXXXXE±XX	X.XXXXXXXE±XX	X.XXXXXXXE±XX	X.XXXXXXXE±XX	
. E	. E	. E	. E	. E	. E	

1	13	26	39	52	65	78
CL(I,J,M)	CL(I,J,M)	CL(I,J,M)	CL(I,J,M)	CL(I,J,M)	CL(I,J,M)	
X.XXXXXXXE±XX	X.XXXXXXXE±XX	X.XXXXXXXE±XX	X.XXXXXXXE±XX	X.XXXXXXXE±XX	X.XXXXXXXE±XX	
. E	. E	. E	. E	. E	. E	

1	13	26	39	52	65	78
CL(I,J,M)	CL(I,J,M)	CL(I,J,M)	CL(I,J,M)	CL(I,J,M)	CL(I,J,M)	
X.XXXXXXXE±XX	X.XXXXXXXE±XX	X.XXXXXXXE±XX	X.XXXXXXXE±XX	X.XXXXXXXE±XX	X.XXXXXXXE±XX	
. E	. E	. E	. E	. E	. E	

1	13	26	39	52	65	78
CH(I,J,M)	CH(I,J,M)	CH(I,J,M)	CH(I,J,M)	CH(I,J,M)	CH(I,J,M)	
X.XXXXXXXE±XX	X.XXXXXXXE±XX	X.XXXXXXXE±XX	X.XXXXXXXE±XX	X.XXXXXXXE±XX	X.XXXXXXXE±XX	
. E	. E	. E	. E	. E	. E	

1	13	26	39	52	65	78
CH(I,J,M)	CH(I,J,M)	CH(I,J,M)	CH(I,J,M)	CH(I,J,M)	CH(I,J,M)	
X.XXXXXXXE±XX	X.XXXXXXXE±XX	X.XXXXXXXE±XX	X.XXXXXXXE±XX	X.XXXXXXXE±XX	X.XXXXXXXE±XX	
. E	. E	. E	. E	. E	. E	

1	13	26	39	52	65
CH(I.J.M)	CH(I.J.M)	CH(I.J.M)	CH(I.J.M)	CH(I.J.M)	CH(I.J.M)
X.XXXXXXXE±	.XXXXXXXE±XX	X.XXXXXXXE±XX	X.XXXXXXXE±XX	X.XXXXXXXE±XX	X.XXXXXXXE±XX
. E	. E	. E	. E	. E	. E

1	5	10	15	20	25	30	35	40	45	50
NUMPTS	(1.2)	(1.3)	(1.4)	(1.5)	(1.6)	(1.7)	(1.8)	(1.9)	(1.10)	
XXXXX	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX	

80 22A

1	5	10	15	20	25	30	35	40	45	50
(2.1)	(2.2)	(2.3)	(2.4)	(2.5)	(2.6)	(2.7)	(2.8)	(2.9)	(2.10)	
XXXXX	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX	

80 22B

1	5	10	15	20	25	30	35	40	45	50
(3.1)	(3.2)	(3.3)	(3.4)	(3.5)	(3.6)	(3.7)	(3.8)	(3.9)	(3.10)	
XXXXX	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX	

80 22C

	1	10	20	30
	[illegible]		[illegible]	[illegible]
Set 23	[illegible]		[illegible]	[illegible]

MOLE = 0 omit cards 15 thru 19, fill ca 22A, 22B, 22C, and cards in set 23.

BBR(1)	BBR(2)	BBR(3)	Card
			15

ABEL(1)	ABEL(2)	ABEL(3)	Card
			16

CSLA(1)	CSLA(2)	CSLA(3)	Card
			17

DEL(1)	DEL(2)	DEL(3)	DEL(4)	DEL(5)	Card
					18A

DEL(6)	DEL(7)	DEL(8)	DEL(9)	DEL(10)	Card
					18B

DEL(11)	DEL(12)	DEL(13)	DEL(14)	DEL(15)	Card
					18C

H 17

C_0/C_4 0.15

DATA

2/8/63

Pass 1 – 3	Curve 1 – 6	Point 1 – 20	α	CL	CHF
J = 1	0° (1)		+04.400000	+00.400000	-00.008000
			+03.300000	+00.300000	-00.006500
			+02.150000	+00.200000	-00.004500
			+01.050000	+00.100000	-00.002000
			+00.000000	+00.000000	+00.0000
	0°	6	-01.250000	-00.100000	+00.0030
	5° (2)		+02.000000	+00.400000	-00.0360
			+00.900000	+00.300000	-00.0335
			-00.150000	+00.200000	-00.0310
			-01.200000	+00.100000	-00.02900
			-02.250000	+00.000000	-00.0270
	5°	6	-03.350000	-00.100000	-00.0255

$C_0/C_4 = 0.15$

H-18

STERN PLANC

DATE	CURVE	POINT	α	CL	CHF
1 - 3	1 - 6	1 - 20			
1	10° [3]		+02.200000	+00.600000	-00.076000
			+ 1.0	+ .5	- .069
			- 0.2	+ .4	- .062
			- 1.4	+ .3	- .056
			- 2.5	+ .2	- .052
			- 3.6	+ .1	- .049
			- 4.8	+ .0	- .046
	10°		- 5.9	- .1	- .043

$C_b/C_f = 0.15$

STERN PLANE T[illegible]

DATA

$C_b/C_f = 0.15$

RUN 1 – 3	CURVE 1 – 6	POINT 1 – 20	α	CL	CHF
1	15°	(4)	+02.65	+00.80	−00.1330
			+1.40	+.70	−.1290
			+0.20	+.60	−.1245
			−0.45	+.55	−.1220
			−1.05	+.50	−.1190
			−1.60	+.45	−.1170
			−2.25	+.40	−.1135
			−2.85	+.35	−.1105
			−3.45	+.30	−.1065
			−4.05	+.25	−.1025
			−4.65	+.20	−.0980
			−5.80	+.10	−.0380
			−7.05	+.00	−.0785
	15°	14	−8.20	−.10	−.0700

STERN PLANE TOM

Pe[illegible]	[illegible]	Point	α	CL	CHF
1 – 3	1 – 6	1 – 20			
1	20° (5)		+02.200000	+00.900000	−00.202000
			+ 0.90	+ .80	− .1970
			− 0.30	+ .70	− .1900
			− 0.95	+ .65	− .1870
			− 1.50	+ .60	− .1840
			− 2.10	+ .55	− .1800
			− 2.70	+ .50	− .1770
			− 3.55	+ .45	− .1735
			− 3.95	+ .40	− .1700
			− 4.60	+ .35	− .1665
			− 5.15	+ .30	− .1625
			− 5.75	+ .25	− .1585
			− 6.35	+ .20	− .1550
			− 7.50	+ .10	− .1485
			− 8.70	+ .00	− .1405
	20°	16	− 9.80	− .10	− .1330

2/9/63

$C_b/C_f = 0.15$

STERN PLANE TO:
T. MARTINETTO

1-5
2/9/63

$C_b/C_f = 0.15$

PAGE	CURVE	POINT	α	CL	CHF
1-3	1-6	1-20			
1	25° (6)		+01.900000	+01.000000	-00.247500
			+ 0.70	+00.90	- .2450
			- 0.55	+ .80	- .2420
			- 1.75	+ .70	- .2385
			- 2.30	+ .65	- .2370
			- 2.90	+ .60	- .2350
			- 3.50	+ .55	- .2335
			- 4.15	+ .50	- .2315
			- 4.70	+ .45	- .2295
			- 5.30	+ .40	- .2270
			- 5.85	+ .35	- .2250
			- 6.40	+ .30	- .2225
			- 7.00	+ .25	- .2200
			- 7.50	+ .20	- .2175
			- 8.65	+ .10	- .2120
			-09.00	+ .00	- .2055
	25		-10.90	- .10	- .1980

STERN PLANE TORQ

c/4 = 0.35

DATA

CARD 1-3	CURVE 1-6	POINT 1-20	α	CL	CHF
2	0° (1)		+04.800000	+00.400000	+00.006000
			+3.5	+.30	+.007
			+2.3	+.20	+.005
			+1.1	+.10	+.002
			+0.0	+.00	+.000
	0	6	-1.3	-.10	-.002
	5 (2)		+02.100000	+00.400000	-00.011000
			+0.9	+.30	-.010
			+0.2	+.25	-.010
			-0.4	+.20	-.011
			-1.0	+.15	-.013
			-1.6	+.10	-.014
			-2.8	+.00	-.016
	5	8	-4.0	-.10	-.016

2/9/80

c/4 = 0.35

STERN PLANE TORO

T. MARTINETTO

DATA

2/9/[illegible]

PART	CURVE	POINT	α	CL	CHF
1 - 3	1 - 6	1 - 20	bbb.XXXXX	bbb.XXXXX	bbb.XXXXX
2	10° (3)		+01.950000	+00.600000	-00.042000
			+ 0.70	+ .50	- .0335
			+ 0.10	+ .45	- .0305
			- 0.60	+ .40	- .0275
			- 1.25	+ .35	- .0260
			- 1.85	+ .30	- .0245
			- 2.50	+ .25	- .0230
			- 3.10	+ .20	- .0230
			- 4.30	+ .10	- .0230
			- 5.40	+ .00	- .0250
	10		- 6.60	- .10	- .0270

$C_b/C_f = 0.35$

STERN PLANE TORQUE
T MARTINETTA

DATA

2/8/63

PAGE	CURVE	POINT	α	CL	CHF
1 – 3	1 – 8	1 – 20			
2	15° (4)		+02.600000	+00.800000	-00.124000
			+ 1.05	+ .70	- .1105
			- 0.40	+ .60	- .0870
			- 1.10	+ .55	- .0730
			- 1.80	+ .50	- .0630
			- 2.50	+ .45	- .0550
			- 3.10	+ .40	- .0500
			- 3.80	+ .35	- .0455
			- 4.50	+ .30	- .0420
			- 5.10	+ .25	- .0390
			- 5.70	+ .20	- .0375
			- 7.00	+ .10	- .0350
			- 8.20	+ .00	- .03[illegible]0
	15	14	- 9.40	- .10	- .0370

$C_b/C_f = 0.35$

STERN PLANE [illegible]

DATA

FIG. 1-3	CURVE 1-6	POINT 1-20	α	CL	CHF
2	20° (5)		+01.500000	+00.800000	-00.190000
			+ 0.10	+ .70	- .1810
			- 0.65	+ .65	- .1740
			- 1.35	+ .60	- .1660
			- 2.20	+ .55	- .1535
			- 3.40	+ .50	- .1335
			- 5.10	+ .45	- .1110
			- 6.20	+ .40	- .0940
			- 6.90	+ .35	- .0800
			- 7.50	+ .30	- .0700
			- 8.20	+ .25	- .0610
			- 8.90	+ .20	- .0540
			- 09.50	+ .15	- .0490
			- 10.20	+ .10	- .0460
			- 11.40	+ .00	- .0430
	20	16	- 12.50	- .10	- .0430

$C_b/C_f = 0.35$

STERN PLANE TORQ

T. MARTINETTO

DATA

2-5 2/1/0

PAD	CURVE	POINT	α	CL	CHF
1-3	1-6	1-20			
2	25 (6)		+01.300000	+00.800000	-00.200000
			+ 0.10	+ .70	- .1960
			- 0.65	+ .65	- .1935
			- 1.30	+ .60	- .1910
			- 2.20	+ .55	- .1890
			- 3.00	+ .50	- .1880
			- 3.90	+ .45	- .1870
			- 4.95	+ .40	- .1860
			- 6.20	+ .35	- .1640
			- 7.90	+ .30	- .1610
			-09.2	+ .25	- .1310
			-10.3	+ .20	- .1020
			-11.3	+ .15	- .0780
			-12.2	+ .10	- .0625
			-13.0	+ .05	- .0540
			-13.7	+ .00	- .0495
	25	17	-14.9	- .10	- .0460

$C_b/C_g = 0.35$

STERN PLANE T...

= 0.50

DATA

1

2/12/6
WMB

PAGE	CURVE	POINT	α	CL	CHF
1 - 3	1 - 6	1 - 20			
J = 3	0° (1)		+05.200000	+00.400000	+00.017500
			+03.85	+ .30	+ .0160
			+02.55	+ .20	+ .0115
			+01.30	+ .10	+ .0065
			+00.00	+ .00	+ .0000
	0	6	-01.30	- .10	- .0050
	5° (2)		+02.800000	+00.500000	+00.021500
			+ 1.45	+ .40	+ .0200
			+ 0.20	+ .30	+ .0160
			- 1.10	+ .20	+ .0100
			- 2.40	+ .10	+ .0030
			- 3.60	+ .00	- .0050
	5	7	- 4.80	- .10	- .0095

$C_b/C_f = 0.50$

STERN PLANE TORQ

2

2/13/63

$C_b/C_4 = 0.50$

PAGE	CURVE	POINT	α	CL	CHF
1 − 3	1 − 6	1 − 20			
3	10° (3)		+02.55 0000	+00.70 0000	+00.022500
			+ 1.15	+ .60	+ .0310
			− 0.25	+ .50	+ .0320
			− 1.50	+ .40	+ .0280
			− 2.80	+ .30	+ .0220
			− 4.10	+ .20	+ .0170
			− 5.30	+ .10	+ .0130
			− 6.50	+ .00	+ .0095
	10	9	− 7.70	− .10	+ .0065

STERN PLANE TEST

DATA

CASE	CURVE	POINT	α	CL	CHF
1 – 3	1 – 6	1 – 20			
3	15°	14	+02.800000	+00.900000	-00.052000
			+00.70	+ .80	+ .001500
			-00.65	+ .70	+ .0230
			-01.20	+ .65	+ .0315
			-01.75	+ .60	+ .0380
			-02.30	+ .55	+ .0425
			-02.95	+ .50	+ .0450
			-03.65	+ .45	+ .0455
			-04.45	+ .40	+ .0450
			-05.90	+ .30	+ .0430
			-07.30	+ .20	+ .0400
			-08.40	+ .10	+ .0370
			-09.35	+ .00	+ .0340
	15	14	-10.25	- .10	+ .0310

$C_b/C_f = 0.50$

2/13/63
WHB

STERN PLANE T...

C/C USD

DATA

DPT	CURVE	POINT	α	CL	CHF
1 - 3	1 - 6	1 - 20			
3	20° (5)		+02.650000	+00.800000	-00.130000
			+01.50	+ .75	- .1220
			+00.20	+ .70	- .0980
			-01.30	+ .65	- .0310
			-02.90	+ .60	- .0120
			-04.15	+ .55	- .0020
			-05.20	+ .50	+ .0130
			-06.10	+ .45	+ .0490
			-06.50	+ .43	+ .0560
			-06.90	+ .40	+ .0640
			-07.60	+ .35	+ .0705
			-08.30	+ .30	+ .0720
			-08.90	+ .25	+ .0715
			-09.45	+ .20	+ .0700
			-10.50	+ .10	+ .0670
			-11.40	+ .00	+ .0650
	20	17	-12.30	- .10	+ .0630

2/17/83
WMB

$C_b/C_f = 0.50$

$C_b/C_f = 0.50$

Page	Card	Point	α	C_L	CHF
1 – 3	1 – 6	1 – 20			
3	25° (6)		+ 3.300000	+00.800000	-00.160000
			+ 1.90	+ .70	– .1530
			+ 0.20	+ .60	– .1455
			– 1.20	+ .55	– .1410
			– 2.15	+ .52	– .1375
			– 3.20	+ .50	– .1250
			– 5.45	+ .45	– .0690
			– 7.10	+ .40	– .0200
			– 8.20	+ .34	+ .0180
			– 9.60	+ .30	+ .0200
			– 10.35	+ .26	+ .0390
			– 11.30	+ .20	+ .0850
			– 11.60	+ .18	+ .0905
			– 12.10	+ .14	+ .0940
			– 12.50	+ .10	+ .0950
			– 13.45	+ .00	+ .0930
	25	17	– 14.50	– .10	+ .0065

2/18/63

STERN PLANE TORQ

T. MACTINETTO

```
      PROGRAM STPLT(INPUT,TAPE5=INPUT,OUTPUT,TAPE6=OUTPUT)
C     UPDATED FORTRAN SOURCE DECK FOR STERN PLANE TORQUE CALCULATIONS
C     FOR USE ON CDC 6000 SERIES COMPUTERS
C
      DIMENSION FSTAB(15)
      DIMENSION DIF(100),CFIR(100),TITLE(25),YDBS(15),BRR(05),
     1ADEL(05),   CSLA(05),DEL(15),CL(15,05,15),CH(15,05,15),
     2CLRAT(05),FRAT(05),ERAT4(15),CLIN(05,15),EELL(05,15),
     3ALPE(05,15),CLEE(05,15),CLERAT(15,05),DELC(15),C(15),
     4CHD(15),AIDEL(15),Z1(15),Z2(15),FACTL(15),CMOMP(15),
     5FACTH(15),ACLC(5,15),ACHC(05,15),X(3),Y(3),Z(3),CA(15),
     6SPATCH(100),PATCH(200),CLPL(15),ZIMP(05),SCCV(05,3),
     7SCC(05),CLDEL(05),DELSC(05),DELCH(05,15),CACHC(05,15),
     8CHBL(15),ZLIFT(15),QH(15),DELRAD(15),ETDLNG(15),CLETAU(15),
     9CNFC(15),FNFC(15),QF(15),CMOMV1(15),CMOMR1(15),CMOMV(15)
      DIMENSION DSUB1(100),DSUB2(50),DSUB3(25),SML(15),
     1CLC(15,5,15),CHC(15,5,15),CFCRAT(15)
      DIMENSION XTRPL(15),XTRMI(15)
      COMMON NDEL,NDEL1,NYDBS,CL,CH,CLIN,NSET,SUB1,
     1SUB2,SUB3,SUB4,SUB5,DSUB1,DSUB2,DSUB3,NSUB,NSUB1,
     2EELL,ADEL,ZK,DEL,ALPE,CLEE,CLRAT,CLERAT,ERAT4,YDBS,
     3BRR,PATCH
      DATA FINISH/6HEND OF/
      SML(1)=1.
      SML(2)=4.
      SML(3)=2.
      SML(4)=4.
      SML(5)=1.5
      SML(6)=2.
      SML(7)=.5
 1    READ                67,(TITLE(I),I=1,24)
 67   FORMAT(12A6/12A6          )
      IF(TITLE(1).EQ.FINISH) GO TO 8000
      PRINT                 68,(TITLE(I),I=1,24)
 68   FORMAT(1H1/1H024X,12A6/1H024X,12A6      )
C
C     INPUT OF SHIP CONSTANTS
C
      READ                10,AP,AT,AF,OMEGA,CB,CF,CT,CR,S,
     1SF,ARE,V,RHO,ZK,PHI,AU,RAD,ALCFAC,CFINC,ZT,
     2EPSLON,S1,S2,S3,NSPARE
      READ                8080,SPECHA
 8080 FORMAT(F13.7            )
C     SAVE READ IN CF AT BEGINNING
      CFINIT=CF
      AFINIT=AF
      CBINIT=CB
      APART=ARE*(ARE+4.21)
      ETA=1.-.0005*PHI*PHI
      CM=(CT+CR)/2.
      ZLAM=CT/CR
      Q=.5*RHO*1.688*V*V*1.688
C
C
C     OUTPUT OF INPUT
```

```
C
      PRINT                  66,AP,CB,CF,AF,CT,CR,AT,CM
 66   FORMAT(1H0///60X,10HINPUT DATA//23X,
     120HAREAS IN SQUARE FEET46X,14HCHORDS IN FEET/35X,
     212HPLANE AREA =F11.5,34X,14HFWD OF STOCK =F11.5/92X,
     314HAFT OF STOCK =F11.5/28X,19HINITIAL FLAP AREA =F11.5,
     443X,5HTIP =F11.5/100X,6HROOT =F11.5/27X,
     520HINITIAL TOTAL AREA =F11.5,42X,6HMEAN =F11.5         )
C
C
      PRINT                  661,SF,OMEGA,V,S,RHO,PHI,
     1SPECHA,RAD,CFINC,EPSLON
 661  FORMAT(///23X,13HSPANS IN FEET43X,
     127HMISC. INPUT WITH DIMENSIONS/33X,
     214HSPAN OF FLAP =F11.5,15X,19HSWEEP ANGLE OF 1/4
     314HCHRD DEGREES =F11.5/90X,16HSPEED IN KNOTS =F11.5/23X,
     424HSTABLZER + STERN PLANE =F11.5,22X,8HDENSITY
     518HLB SEC SQ/FT 4TH =F11.5/77X,20HTRAILING EDGE ANGLE
     69HDEGREES =F11.5/22X,25HFOR CHANGING PLANE AREA =F11.5,24X,
     724HWEIGHTED RADIUS INCHES =F11.5/85X,15HINITIAL DEL CF
     86HFEET =F11.5/83X,23HBALANCE EPSILON LB-IN =F11.5              )
C
C
C     INPUT OF CONTROL CHARACTERS
C
      READ                   2,NYDBS,NT     ,NDEL1,NMODE,NDEL
 10   FORMAT(5E13.7        )
 2    FORMAT(5I5           )
      NTTEST=1
      PRINT                  662,ARE,ZK,AU,ALOFAC,ZLAM,
     1NT
 662  FORMAT(1H022X,24HDIMENSIONLESS INPUT DATA/33X,
     114HASPECT RATIO =F11.5/34X,13HCONSTANT ZK =F11.5/30X,
     217HFRICTION FACTOR =F11.5/29X,18HALLOWANCE FACTOR =F11.5/
     334X,13HTAPER RATIO =F11.5/24X,
     423HMAX NO. OF ITERATIONS =I5                )
C
C     CORRECT OPMODE TO GET BR ON CL RATIO TABLE
C     AND TO SPECIFY READ IN CL OR LOOKED UP CL
C
C
      READ                   10,(YDBS(I),I=1,NYDBS)
      DO 19 I=1,NYDBS
      DELC(I)=(CR-CT)*YDBS(I)
 19   C(I)=CR-DELC(I)
      IF(NT)664,664,663
 664  NTTEST=0
      READ                   3,(BRR(J),J=1,3)
      READ                   10,(DEL(M),M=1,NDEL1)
      CFCRAT(4)=CF/C(4)
      READ                   10,(CLBL(M),M=1,NDEL1)
      READ                   10,(CHBL(M),M=1,NDEL1)
      GO TO 666
C
C
```

```
C
C
C      INPUT OF DIMENSIONED QUANTITIES
C
 663   READ                   3,(BRR(J),J=1,3),(ADEL(J),J=1,3),
     1(CSLA(J),J=1,3)
 3     FORMAT(3E13.7                          )
       DO 209 J=1,3
       ZIMP(J)=ARE*.1/CSLA(J)
       IF (ZIMP (J)-.599999)2099,2098,2098
 2099  ORNGE=ZIMP (J)
       CVAR=3.0
       GO TO 6666
 2098  IF (ZIMP (J)-6.00001)209,209,2099
 209   CONTINUE
C
       READ                   10,(DEL(M),M=1,NDEL1)
C      6666 A ERROR RETURN WRITE AT END OF PROGRAM
C
C      COEFFICIENTS WILL BE BUILT INTO THE PROGRAM
C
C      COMPUTATION OF TABLE ON PAGE 5
C
       CTOT=CB+CF
C      THERE WILL BE I EQUATIONS FOR ERAT4(I)
       IF(ZLAM-.24999999)99,200,200
 200   IF(ZLAM-1.000999)201,201,99
 99    ORNGE=ZLAM
       GO TO 6666
 201   ERAT4(1)=1.460-.900*ZLAM+.240*ZLAM*ZLAM
       ERAT4(2)=1.2129999-.55399988*ZLAM+.13599990*ZLAM*ZLAM
       ERAT4(3)=     -.110*ZLAM+.01333341*ZLAM*ZLAM+.95666667
       ERAT4(4)=.76333334+.32999991*ZLAM-.93333258E-01*ZLAM*ZLAM
       ERAT4(5)=.43567852+ZLAM*(1.985756+ZLAM*(-2.0392058+
     1ZLAM*(1.2058102-ZLAM*0.32197085 )))
       ERAT4(6)=.45416344E-01+ZLAM*(5.1443329+ZLAM*(
     1-8.1702714+ZLAM*(6.65026-ZLAM* 2.1401547)))
       ERAT4(7)=2.40
       PRINT                  7011
 7011  FORMAT(1H158X,13HE RATIO TABLE//1H 46X,
     145HE RATIO 4 AS A FUNCTION OF Y/(B/2) AND LAMBDA///   )
       PRINT                  70,ZLAM,(YOBS(I),ERAT4(I),I=1,NYOBS)
 70    FORMAT(1H039X,7HY/(B/2)16X,7HE RATIO011X,
     18HLAMBDA =E15.8/(1H036X,E15.8,E23.8)        )
       IF (NMODE) 1919,9999,1919
 9999  NSET=2
       NSUB=0
       PRINT                  900
 900   FORMAT(1H0///1H029X,26HTHE LIFT AND HINGE MOMENT
     145HCOEFFICIENTS ARE OBTAINED FROM INPUT POINTS.                )
       CALL OPMODE
       IF(NSUB)8787,1106,8787
 1919  NSET=1
       NSUB=0
       PRINT                  901
```

```
 901  FORMAT(1H0///1H040X,26HTHE LIFT AND HINGE MOMENT
     123HCOEFFICIENTS ARE INPUT.                        )
      CALL OPMODE
      IF(NSUB)8787,1106,8787
 8787 PRINT                 8788
 8788 FORMAT(1H141X,35HSEE PREVIOUS PRINTOUT TO DETERMINE
     115HERROR IN OPMODE                 )
      GO TO 1
C
C     20 STARTS THE COMPUTATION AND CORRECTION LOOP
C
 1106 L=1
      CFIR(1)=CFINIT
      FK1=.2*S/(3.*AT)
 20   DO 21 I=1,NYDBS
      CFCRAT(I)=CF/C(I)
      IF(CFCRAT(I)-.14999999)205,206,206
 205  ORNGE=CFCRAT(I)
      CVAR=1.0
      GO TO 6666
 206  IF(CFCRAT(I)-.600)207,207,208
 208  ORNGE=CFCRAT(I)
      CVAR=2.0
      GO TO 6666
 207  GO TO 21
 21   CONTINUE
      BR=CB/CF
      DO 22 I=1,NYDBS
      CHD(I)=CFCRAT(I)*(-.17987426E-01+CFCRAT(I)*(.06127221+
     1CFCRAT(I)*(-.05023323+CFCRAT(I)*.01934741)))-
     2.76431806E-02
      AIDEL(I)=CFCRAT(I)*(-2.3144147+CFCRAT(I)*(3.6248806+
     1CFCRAT(I)*(-4.6860865+CFCRAT(I)*2.7272692)))-
     2.10356066
      Z1(I)=-AIDEL(I)/.575
 22   Z2(I)=-CHD(I)/.00872
      FK2=.2*SF/3.*CF/AF
      DO 23 I=1,NYDBS
      FACTL(I)=SML(I)*C(I)*Z1(I)*FK1
 23   FACTH(I)=SML(I)*Z2(I)*FK2
C
C     BEFORE CORRECTING THE COEFFICIENTS THE TABLES ON
C     PAGES 12 AND 13 MUST BE WRITTEN OUT
C
      PRINT                 8484,L,CF,CB,AF,BR
 8484 FORMAT(1H150X,25HTHIS IS ITERATION NUMBER I3////4X,
     120HCHORD AFT OF STOCK =E15.8,9X,20HCHORD FWD OF STOCK =E15.8,14X,
     211HFLAP AREA =E15.8//45X,24HBALANCE RATIO COMPUTED =E15.8          )
      PRINT                 1190,(YDBS(I),DELC(I),C(I),CFCRAT(I),
     1AIDEL(I),Z1(I),CHD(I),Z2(I),I=1,NYDBS)
 1190 FORMAT(1H044X,36HCORRECTION TO CF/C AND COEFFICIENTS
     18HOBTAINED//6X,7HY/(B/2)9X,7HDELTA C13X,1HC14X,
     24HCF/C7X,14H    AIDEL     8X,2HK110X,12H    CHD     8X,
     32HK2/(2X,8E16.8)          )
      CFCF=CF*CF
```

```
      PRINT                    1191,(YDBS(I),SML(I),C(I),Z1(I),
     1FACTL(I),CF,CFCF,Z2(I),FACTH(I),I=1,NYDBS)
 1191 FORMAT(1H036X,33HINTEGRATION FACTORS FOR LIFT AND
     125HHINGE MOMENT COEFFICIENTS//6X,7HY/(B/2)8X,
     22HSM14X,1HC12X,2HK19X,8HFACTOR L9X,2HCF8X,
     310HCF SQUARED8X,2HK29X,8HFACTOR H/(3X,9F14.7)      )
C
C     CORRECTION FOR HINGE MOMENT AND LIFT COEFFICIENTS
C
      DO 800 J=1,3
      DO 799 I=1,NYDBS
      DO 799 M=1,NDEL1
      CLC(I,J,M)=FACTL(I)*CL(I,J,M)
 799  CHC(I,J,M)=FACTH(I)*CH(I,J,M)
      PRINT                    777
 777  FORMAT(1H139X,33HTABLES OF AVERAGE LIFT AND HINGE
     119HMOMENT COEFFICIENTS/1H 44X,17HAS A FUNCTION OF
     225HTHE ORIGINAL COEFFICIENTS          )
      PRINT                    7777,BRR(J),(DEL(M),M=1,NDEL1)
 7777 FORMAT(1H01X,5HBR   =E15.8/54X,25HAVERAGE LIFT COEFFICIENTS//
     16X,7HY/(B/2)9X,8HFACTOR L4X,8HDEL(I) =(F8.5,5F16.5/
     242X,F8.5,5F16.5)              )
      DO 5555I=1,NYDBS
 5555 PRINT                    7070,YDBS(I),FACTL(I),(CLC(I,J,M),
     1M=1,NDEL1)
 7070 FORMAT(1H 1X,8E16.8/(34X,6E16.8)           )
C
C
      DO 7000 M=1,NDEL1
      DUMDUM=CLC(1,J,M)
      DO 6999 I=2,NYDBS
 6999 DUMDUM=DUMDUM+CLC(I,J,M)
 7000 ACLC(J,M)=DUMDUM
      PRINT                    7002,(ACLC(J,M),M=1,NDEL1)
 7002 FORMAT(1H 6X,27HAVERAGE LIFT COEFFICIENTS =(6F16.8/
     135X,6E16.8)                  )
      PRINT                    5557
 5557 FORMAT(1H050X,33HAVERAGE HINGE MOMENT COEFFICIENTS/
     155X,21HFOR SAME DEL AS ABOVE//6X,7HY/(B/2)9X,8HFACTOR H   )
      DO 5556 I=1,NYDBS
 5556 PRINT                    7070,YDBS(I),FACTH(I),
     1(CHC(I,J,M),M=1,NDEL1)
      DO 6998 M=1,NDEL1
      DUMDUM=CHC(1,J,M)
      DO 6997 I=2,NYDBS
 6997 DUMDUM=DUMDUM+CHC(I,J,M)
 6998 ACHC(J,M)=DUMDUM
      PRINT                    5550,(ACHC(J,M),M=1,NDEL1)
 5550 FORMAT(1H 6X,27HAVERAGE HINGE MOMENT COEFF =(6F16.8/
     135X,6E16.8)                 )
 800  CONTINUE
      DO 1001 M=1,NDEL1
      DO 1000 J=1,3
      X(J)=BRR(J)
 1000 Y(J)=ACLC(J,M)
```

```
      CALL PARA (X,Y,A,B,D,S1,SPATCH)
 1001 CLBL(M)=BR*(B+BR*A)+D
C
C     STREAM LINE CURVATURE CORRECTION
C
      X(1)=.2
      X(2)=.4
      X(3)=.6
      DO 1007 J=1,3
      SCCV(J,1)=.326948+ZIMP(J)*(.99243073E-01+ZIMP(J)*(
     1-.54308508E-02+ZIMP(J)*(-.81285062E-03+ZIMP(J)*
     2.90715143E-04)))
C
      SCCV(J,2)=.26836844+ZIMP(J)*(.95015266E-01+ZIMP(J)*(
     1.31903812E-02+ZIMP(J)*(-.31370999E-02+ZIMP(J)*
     2.27182373E-03)))
C
      SCCV(J,3)=.19913176+ZIMP(J)*(.98413575E-01+ZIMP(J)*(
     1-.34114450E-03+ZIMP(J)*(-.22418348E-02+ZIMP(J)*
     2.20449749E-03)))
C
      Y(1)=SCCV(J,1)
      Y(2)=SCCV(J,2)
      Y(3)=SCCV(J,3)
      CALL PARA (X,Y,A,B,D,S1,SPATCH)
 1007 SCC(J)=CFCRAT(4)*(B+CFCRAT(4)*A)+D
      FRAT(1)=CFCRAT(4)*(3.6911194+CFCRAT(4)*(-5.3006265
     1+CFCRAT(4)*(4.7559953-CFCRAT(4)*2.0279548)))+
     2.3009245
      FRAT(2)=CFCRAT(4)*(2.9318192+CFCRAT(4)*(-4.0625912
     1+CFCRAT(4)*(4.256416-CFCRAT(4)*1.9114248)))+
     2.23854536
      FRAT(3)=CFCRAT(4)*(2.4898177+CFCRAT(4)*(-4.3123554
     1+CFCRAT(4)*(6.4832962-CFCRAT(4)*3.2634041)))+
     2.91151472E-01
      PRINT                670
 670  FORMAT(1H129X,34HCALCULATIONS OF VARIOUS CONSTANTS
     139HAND TABLES OF HINGE MOMENT COEFFICIENTS                    )
      DO 1009 J=1,3
      PRINT                8182
 8182 FORMAT(1H055X,20HCALCULATION OF DELSC/1H08X,
     13HBRR19X,3HSCC19X,3HETA21X,10H   FRAT   12X,
     25HAPART17X,5HDELSC        )
      CLDEL(J)=ADEL(J)*CSLA(J)*Z1(4)
      DELSC(J)=SCC(J)*FRAT(J)*ETA/APART*CLDEL(J)
      PRINT                8282,BRR(J),SCC(J),ETA,
     1FRAT(J),APART,DELSC(J)
 8282 FORMAT(    6E22.8         )
      DO 1008 M=1,NDEL1
      DELCH(J,M)=DELSC(J)*DEL(M)
 1008 CACHC(J,M)=ACHC(J,M)-DELCH(J,M)
      PRINT                1110
 1110 FORMAT(1H046X,34HTABLE OF HINGE MOMENT COEFFICIENTS/46X,
     136HWITH STREAMLINE CURVATURE CORRECTION         )
 1009 PRINT                1010,BRR(J),(DEL(M),ACHC(J,M),
```

```
     1DELCH(J,M),CACHC(J,M),M=1,NDEL1)
1010 FORMAT(1H01X,15HBALANCE RATIO =F15.8//9X,
    126HDEL PLANE DEFLECTION ANGLE5X,23HUNCORRECTED AVERAGE CHF17X
    2,7HDEL CHF23X,13HCORRECTED CHF/(E29.8,F31.8,2E32.8)           )
C
C
C
      PRINT                  903,L,CF,CB,AF,BR
 903  FORMAT(1H149X,26HTHIS WAS ITERATION NUMBER I3//4X,
    120HCHORD AFT OF STOCK =E15.8,9X,20HCHORD FWD OF STOCK =E15.8,
    214X,11HFLAP AREA =E15.8//45X,24HBALANCE RATIO COMPUTED =E15.8
    3                   )
C
C
C     TOTAL LIFT FORCE AND HYDRODYNAMIC TORQUE
C
      PRINT                  6637
6637 FORMAT(1H038X,30HTABLE OF TOTAL LIFT FORCE AND
    119HHYDRODYNAMIC TORQUE//2X,21HDEL PLANE DEFLECTION
    25HANGLE11X,4HCLBL17X,10HTOTAL LIFT17X,4HCHBL19X,
    319H          QH                                   )
      GO TO 669
 666  PRINT                  3737
3737 FORMAT(1H138X,30HTABLE OF TOTAL LIFT FORCE AND
    119HHYDRODYNAMIC TORQUE//2X,21HDEL PLANE DEFLECTION
    25HANGLE11X,4HCLBL17X,10HTOTAL LIFT17X,4HCHBL19X,
    319H          QH                 )
 669  DO 38 M=1,NDEL1
      IF(NTTEST)668,668,667
 667  DO 37 J=1,3
      X(J)=BRR(J)
 37   Y(J)=CACHC(J,M)
      CALL PARA (X,Y,A,B,D,S1,SPATCH)
      CHBL(M)=BR*(BR*A+B)+D
 668  ZLIFT(M)=CLBL(M)*Q*AT
      QH(M)=CHBL(M)*Q*AF*CF*12.
 38   PRINT                  3838,DEL(M),CLBL(M),ZLIFT(M),
    1CHBL(M),QH(M)
3838 FORMAT(E20.8,E32.8,E24.8,E23.8,E27.8)
C
C     COMPUTE NORMAL FORCE AND FRICTION FORCE
C
      ETA0=CFCRAT(4)*(1.1771127+CFCRAT(4)*(-2.6485433+
    1CFCRAT(4)*(4.6304586-CFCRAT(4)*2.8205127)))+
    2.39975747E-01
      ETA2=2.0376/.8*CFCRAT(4)-2.547
      PRINT                  8383,ETA0,ETA2
8383 FORMAT(1H0///50X,6HETA0 =E15.8//50X,6HETA2 =E15.8///    )
      PRINT                  2222
2222 FORMAT(1H040X,35HTABLE OF NORMAL FORCE ON PLANE AND
    115HFRICTION TORQUE//3X,14H      ANGLE     2X,
    210HIN RADIANS7X,4HCLBL9X,6HCLETA08X,6HETDLNG10X,3HCNF
    311X,3HFNF6X,12HSTABLZR LIFT7X,2HQF           )
C
      DO 45 M=1,NDEL1
```

```
      DELRAD(M)=3.14159265/180.*DEL(M)
      ETDLNG(M)=-ETA2*DELRAD(M)
      CLETA0(M)=ETA0*CLBL(M)
      CNFC(M)=CLETA0(M)+ETDLNG(M)
      FNFC(M)=CNFC(M)*Q*AP
      FSTAB(M)=ZLIFT(M)-FNFC(M)*COS (DELRAD(M))
      QF(M)=FNFC(M)*AU*RAD
 45   PRINT                     4545,DEL(M),DELRAD(M),CLBL(M),
     1CLETA0(M),ETDLNG(M),CNFC(M),FNFC(M),FSTAB(M),QF(M)
 4545 FORMAT(3X,9E14.7         )
C
C     ALLOWANCE TORQUE AND TOTAL TORQUE
C
      PRINT                     2323
 2323 FORMAT(1H043X,30HTABLE OF ALLOWANCE TORQUE AND
     112HTOTAL TORQUE//3X,5HANGLE9X,3HFNF11X,7HQH + QA8X,7HQH - QA7X,
     27HQH + QF8X,7HQH - QF10X,2HQA9X,12HQH + QA + QF3X,
     312HQH - QF - QA                    )
      DO 48 M=1,NDEL1
      QA(M)=FNFC(M)*ALOFAC*12.*CF
      CMOMV1(M)=QH(M)+QA(M)
      CMOMR1(M)=QH(M)-QA(M)
      CMOMV(M)=CMOMV1(M)+QF(M)
      CMOMR(M)=CMOMR1(M)-QF(M)
      XTRPL(M)=QH(M)+QF(M)
      XTRMI(M)=QH(M)-QF(M)
 48   PRINT                     4848,DEL(M),FNFC(M),CMOMV1(M),CMOMR1(M),
     1        XTRPL (M),XTRMI (M),QA(M),CMOMV(M),
     2CMOMR(M)
 4848 FORMAT(F11.5,8E15.5                )
      BCMOMV=CMOMV(1)
      DO 49 M=2,NDEL1
      IF(      CMOMV(M) -BCMOMV)49,49,490
 490  BCMOMV=CMOMV(M)
 49   CONTINUE
C
      BCMOMR=ABS (CMOMR(1))
      DO 50 M=2,NDEL1
      IF(ABS (CMOMR(M))-BCMOMR)50,50,491
 491  BCMOMR=ABS (CMOMR(M))
 50   CONTINUE
      DIF(L)=BCMOMV-BCMOMR
      IF(NT-1)8585,8585,5440
 5440 IF(ABS (DIF(L))-EPSLON)5454,5454,5050
 5050 IF(L-1)5011,5011,5012
 5011 IF(DIF(L))5013,4014,4014
 5013 CFINC=-CFINC
 4014 CF=CFINIT+CFINC
      GO TO 5020
 5012 IF(NT-L)5014,5014,5019
C
C     FALSE POSITION
C
 5019 CF=(DIF(L-1)*CFIR(L)-DIF(L)*CFIR(L-1))/(DIF(L-1)-DIF(L))
 5020 AFINCR=(CF-CFINIT)*SPECHA
```

```
      AF=AFINIT+AFINCR
      L=L+1
      CFIR(L)=CF
      CB=CTOT-CF
      GO TO 20
C
C     5014 ERROR RETURN WRITE OUT FALSE POSITION
C     VARIABLES
C
 5454 PRINT                  5666,CF
 5666 FORMAT(1H166X,19HTHE FINAL ANSWER IS//67X,4HCF =F15.8          )
      GO TO 1
C
C
 6666 PRINT                  6667,ORNGE,CVAR
 6667 FORMAT(1H140X,28HINDEPENDENT VARIABLE OUT OF
     116HACCEPTABLE RANGE//28X,22HINDEPENDENT VARIABLE =E15.8,
     26X,6HCVAR =E15.8)
 5014 PRINT                  5414,BCMOMR,BCMOMV
 5414 FORMAT(1H159X,12HERROR RETURN/60X,11HNT EXCEDDED/45X,
     118HRESTORING MOMENT =E15.8/45X,
     218HUPSETTING MOMENT =E15.8                    )
      PRINT                  5114,(DIF(L),CFIR(L),L=1,NT)
 5114 FORMAT(1H047X,30HAMOUNTS TORQUES ARE UNBALANCED30X,
     115HCF FOR NT TRIES/(47X,E23.8,37X,F15.8)                 )
      GO TO 1
 8585 PRINT                  8686,CF,DIF(1)
 8686 FORMAT(1H166X,19HTHE FINAL ANSWER IS//67X,4HCF =E15.8//
     11H063X,22HAMOUNT OF UNBALANCE IS//63X,8HDIF(1) =E15.8        )
      GO TO 1
 8000 STOP
      END
C     UPDATED FORTRAN SOURCE DECK FOR MODES 1 AND 2
C
      SUBROUTINE CPMODE
      COMMON NDEL,NDEL1,NYDBS,CL,CH,CLIN,NSET,SUB1,
     1SUB2,SUB3,SUB4,SUB5,DSUB1,DSUB2,DSUB3,NSUB,NSUB1,
     2EELL,ADEL,ZK,DEL,ALPE,CLEE,CLRAT,CLERAT,FRAT4,YDBS,
     3BRR,PATCH
C     SAME COMMON FOR MAIN PROGRAM
      DIMENSION CL(15,5,15),CH(15,5,15),CLIN(5,15),DSUB1(100),
     1DSUB2(50),DSUB3(25),EELL(5,15),ADEL(5),DEL(15),ALPE(5,15),
     2CLEE(5,15),CLRAT(5),CLERAT(15,5),FRAT4(15),YDBS(15),BRR(5),
     3PATCH(200)
      DIMENSION NUMPTS(5,15)    ,ADL(5,15,20)    ,CLN(5,15,20),
     1CHN(5,15,20)    ,CCOMV(200)     ,TABLV(200)
      TEST=0.0
      DO 800J=1,3
      DO 800M=1,NDEL
      EELL(J,M)=-ADEL(J)*ZK*DEL(M)
 800  ALPE(J,M)=-EELL(J,M)
      IF(NSET-1)11,11,10
 11   READ                 51,((CLIN(J,M),M=1,NDEL),J=1,3)
 51   FORMAT(4F13.7     )
 202  DO 204 J=1,3
```

```
      DO 2041 I=1,NYDBS
2041  READ              2042,(CL(I,J,M),M=1,NDFL1)
      DO 2043 I=1,NYDBS
2043  READ              2042,(CH(I,J,M),M=1,NDEL1)
2042  FORMAT(6E13.7        )
204   CONTINUE
      GO TO 9998
10    CONTINUE
      DO 900 J=1,3
900   READ              901,(NUMPTS(J,M),M=1,NDEL1)
901   FORMAT(10I5      )
      DO 903 J=1,3
      DO 903 M=1,NDEL1
      NPTS=NUMPTS(J,M)
      DO 903 NU=1,NPTS
903   READ              902,ADL(J,M,NU),CLN(J,M,NU),
     1CHN(J,M,NU)
902   FORMAT(3F10.6          )
      DO 918 J=1,3
      JJ=J
      PRINT                500,JJ
500   FORMAT(1H159X,22HINPUT POINTS FOR PAGE    I3             )
      DO 918 M=1,NDEL1
      MM=M
      PRINT                501,MM
501   FORMAT(1H0      9X,14HCURVE NUMBER =I3                   )
      NPTS=NUMPTS(J,M)
918   PRINT                919,       (ADL(J,M,NU),CLN(J,M,NU),
     1CHN(J,M,NU),NU=1,NPTS)
919   FORMAT(1H015X,12HALPHA POINTS 28X,
     218HLIFT COEFF. POINTS27X,19HHINGE MOMENT POINTS/(F27.6,F42.6,
     3F45.6                     )                                  )
C
C     CALCULATION OF CLIN(J,M)
C
      DO 905 J=1,3
      DO 905 M=1,NDEL
      NPTS=NUMPTS(J,M)
      DO 904 NU=1,NPTS
      CCOMV(NU)=ADL(J,M,NU)
904   TABLV(NU)=CLN(J,M,NU)
      TILT=1.0
      COMV=ALPE(J,M)
      TEST=0.0
      CALL TABLOK(COMV,CCOMV,ANS,TABLV,NPTS,TEST,
     1S1,S2)
      IF(TEST)905,905,906
905   CLIN(J,M)=ANS
9998  PRINT                7031
7031  FORMAT(1H158X,14HCL RATIO TABLE//34X,
     140HCL RATIO AS A FUNCTION OF CB/CF AND DEL
     223HPLANE DEFLECTION ANGLES        )
7777  DO 702 J=1,3
      DO 701 M=1,NDEL
701   CLEE(J,M)=CLIN(J,M)/EELL(J,M)
```

```
      CLRAT(J)=(CLEE(J,2)+2.*CLEE(J,3)+3.*CLEE(J,4))/6.
      PRINT              600,BRR(J)
  600 FORMAT(1H01X,15HBALANCE RATIO =F6.3                         )
      PRINT              703,(DEL(   M),ALPE(J,M),CLIN(J,M),
     1CLEE(J,M),M=1,NDEL)
  702 PRINT              704,CLRAT(J)
  703 FORMAT(1H01X,17HDEFLECTION ANGLES9X,4HALPE66X,2HCL17X,
     17HCL/EELL/(F18.8,E20.8,E68.8,E21.8)          )
  704 FORMAT(1H052X,10HCL RATIO =E15.8            )
      PRINT              7050
 7050 FORMAT(1H060X,10HCL/E TABLE              )
      PRINT              7051,(CLRAT(J),J=1,3)
 7051 FORMAT(1H047X,11HCL RATIO1 =E15.8,1X,11HCL RATIO2 =E15.8,1X,
     111HCL RATIO3 =E15.8           )
C
      DO705I=1,NYDBS
      DO705J=1,3
  705 CLERAT(I,J)=CLRAT(J)/ERAT4(I)
      PRINT              7052,(YDBS(I),ERAT4(I),CLERAT(I,1),
     1CLERAT(I,2),CLERAT(I,3),I=1,NYDBS)
 7052 FORMAT(1H08X,7HY/(B/2)23X,5HERAT416X,
     114HCL E RATIO(I1)14X,14HCL E RATIO(I2)14X,14HCL E RATIO(I3)/(
     2F22.8,E27.8,F25.8,2E28.8)         )
C
C
      IF (NSET-1) 913,913,914
C
C     CALCULATION OF CL(I,J,M)
C
C
C
  914 DO 9081 J=1,3
      TILT=4.0
      DO 9081 M=1,NDEL1
      NPTS=NUMPTS(J,M)-1
      DO 9081 I=1,NYDBS
      DAMNTM=-1./CLERAT(I,J)
      DO 907NU=1,NPTS
      NPTEST=0
      XTEST=(ADL(J,M,NU+1)*CLN(J,M,NU)-ADL(J,M,NU)*
     1CLN(J,M,NU+1))/(DAMNTM      *(CLN(J,M,NU)-CLN(J,M,NU+1))
     2-(ADL(J,M,NU)-ADL(J,M,NU+1)))
      IF ( CLN(J,M,NU)-XTEST)909,908,9111
 9111 IF ( CLN(J,M,NU+1)-XTEST)908,909,9071
 9071 NPTEST=1
  907 CONTINUE
  908 IF(NPTEST)909,9081,909
 9081 CL(I,J,M)=XTEST
C
C     CALCULATION OF CH(I,J,M)
      DO 911 J=1,3
      DO 911 M=1,NDEL1
      DO 911 I=1,NYDBS
      NPTS=NUMPTS(J,M)
      DO 910 NU=1,NPTS
```

```
      CCOMV(NU)=CLN(J,M,NU)
 910  TABLV(NU)=CHN(J,M,NU)
      TILT=2.0
      COMV=CL(I,J,M)
      TEST=0.0
      CALL TABLOK(COMV,CCOMV,ANS,TABLV,NPTS,TEST,
     1S1,S2)
      IF(TEST)911,911,906
 911  CH(I,J,M)=ANS
 913  DO 1108 J=1,3
      PRINT                 1107
 1107 FORMAT(1H143X,23HTABLES OF HINGE MOMENT
     121HAND LIFT COEFFICIENTS        )
      PRINT                 1109,BRR(J),(DEL(M),M=1,NDEL1)
 1109 FORMAT(6H0 BR =E15.8/1H 47X,17HLIFT COEFFICIENTS//8X,7HY/(B/2)
     16X,8HDEL(1) =(F10.7,5F18.7/29X,6F18.7)          )
      DO 1100 I=1,NYDBS
 1100 PRINT                 1110,YDBS(I),(CL(I,J,M),M=1,NDEL1)
 1110 FORMAT(1H02X,E18.8,(6E18.8/21X,6E18.8)                   )
      PRINT                 1111
 1111 FORMAT(1H052X,25HHINGE MOMENT COEFFICIENTS      )
      DO 1200 I=1,NYDBS
 1200 PRINT                 1110,YDBS(I),(CH(I,J,M),M=1,NDEL1)
 1108 CONTINUE
      GO TO 916
 906  PRINT                 912,TILT
 912  FORMAT(1H110X,6HTILT =F4.2/1H010X,11HTILT = 1.0
     147HMEANS CLIN TILTED. TILT = 2.0 MEANS CL TILTED.
     228HTILT = 3.0 MEANS CH TILTED.                 )
      NSUB=1
      GO TO 916
 909  PRINT                 915,TILT ,XTEST
 915  FORMAT(1H110X,6HTILT =F4.2,10X,7HXTEST =E15.8/1H010X,
     131HTILT = 4.0 MEANS XTEST TILTED.              )
      NSUB=1
 916  RETURN
      END
C     UPDATED FORTRAN DECK FOR SUBROUTINE TABLOK
C
C     BOTH WAYS TABLE LOOK UP.
C
      SUBROUTINE TABLOK(COMV,CCOMV,ANS, TABLV,NIL,TEST,S1,S2)
      DIMENSIONCCOMV(500), TABLV(500),PATCH(500)
      S1=S1+1.
      IF(CCOMV(1)-CCOMV(NIL))1400,1201,1300
 1201 PRINT              1209
 1209 FORMAT(1H140X,29HNO OUTPUT CCOMV(1)=CCOMV(NIL)       )
      TEST=1.
      GO TO 9999
C     THERE ARE ONLY TWO CASES WHEN COMV FALLS
C     INTO EITHER AN ASCENDING OR DESCENDING LIST
C
C     START DESCEND LOOK UP
 1300 IF(COMV-CCOMV(NIL))1100,1101,1102
 1100 PRINT                 1103,COMV,CCOMV(NIL),S1,CCOMV(1)
```

```
 1103 FORMAT(1H118X,6HCOMV= E16.8,2X,7HCCOMV= E16.8,2X,4HS1= F7.2,
     12X,4HCC= E16.8                                     )
      TEST=1.
      GO TO 9999
 1101 ANS=TABLV(NIL)
      GO TO 9999
 1102 LOL=1
      IF(COMV-CCOMV(LOL))1104,1105,1100
 1105 ANS=TABLV(LOL)
      GO TO 9999
 1104 IF(COMV-CCOMV(LOL+1))1107,1108,1109
 1108 ANS=TABLV(LOL+1)
      GO TO 9999
 1107 LOL=LOL+1
      GO TO 1104
 1109 BB=CCOMV(LOL+1)-CCOMV(LOL)
      DINC=TABLV(LOL+1)-TABLV(LOL)
      CL=COMV-CCOMV(LOL)
      ANS=TABLV(LOL)+CL/BB*DINC
      GO TO 9999
C     ASCEND ASCEND SAME AS OLD BETA
C
 1400 IF(COMV-CCOMV(NIL))100,200,1100
 200  ANS=TABLV(NIL)
      GO TO 9999
 100  LOL=1
      IF(COMV-CCOMV(LOL))1100,2000,3000
 2000 ANS=TABLV(LOL)
      GO TO 9999
 3000 IF(COMV-CCOMV(LOL+1))1109,3002,3003
 3002 ANS=TABLV(LOL+1)
      GO TO 9999
 3003 LOL=LOL+1
      GO TO 3000
C
C     END OF ASCEND ASCEND
C
 9999 RETURN
      END
      SUBROUTINE PARA(X,Y,A,B,C,S1,SPATCH)
      DIMENSION X(3),Y(3),SPATCH(100)
      XDUM1=X(1)
      XDUM2=X(2)
      XDUM3=X(3)
      YDUM1=Y(1)
      YDUM2=Y(2)
      YDUM3=Y(3)
      ADUM=((YDUM1-YDUM2)/(XDUM1-XDUM2)-(YDUM1-YDUM3)/(XDUM1-XDUM3))
     1/(XDUM2-XDUM3)
      BDUM=(YDUM1-YDUM2)/(XDUM1-XDUM2)-(XDUM1+XDUM2)*ADUM
      CDUM=YDUM1-XDUM1*XDUM1*ADUM-XDUM1*BDUM
      A      =ADUM
      B      =BDUM
      C      =CDUM
      RETURN
      END
```

```
Card
No

1                          STERN PLANE TORQUE CALCULATIONS
2                     SSN TRY NO. 1
3   98.62          207.19        69.88         23.42         2.33333        ⎫
4   4.416666667    11.16667      19.03125      13.625        15.4270833     ⎪
5   1.792          (SPEED)       1.9906        .568          18.0           ⎬ Sample Ship Data
6   0.20           5.23          0.06          0.083333                     ⎪
7   1000.0                                                                  ⎪
8   18.5                                                                    ⎭
9        7     5     6     0     6
10 { .00       E+00 .2       E+00 .4       E+00 .6       E+00 .8       E+00
   { .9        E+00 .1       E+01 .        E    .        E    .        E
11   .15       E+00 .35      E+00 .50      E+00 .        E    .        E
12  -.460      E+00-.530     E+00-.650     E+00
13   .089      E+00 .079     E+00 .085     E+00
18 { .0        E+00 .5       E+01 .10      E+02 .15      E+02 .20      E+02
   { .25       E+02
22A      6      6      8     14     16     17
22B      6      8     11     14     16     17
22C      6      7      9     14     17     17      δ     Curve No   Cb/Cf   j
Set 1 23 +04.400000+00.400000-00.008000             0°    1          0.15    1
         +03.300000+00.300000-00.006500
         +02.150000+00.200000-00.004500
         +01.050000+00.100000-00.002000
No of    +00.000000+00.000000+00.000000
Points   -01.250000-00.100000+00.003000
   6 —   +02.000000+00.400000-00.036000          —  5°    2
         +00.900000+00.300000-00.033500
         +00.150000+00.200000-00.031000
         -01.200000+00.100000-00.029000
         -02.250000+00.000000-00.027000
   6 —   -03.350000-00.100000-00.025500
         +02.200000+00.600000-00.076           —  10°   3
         +01.000000+00.500000-00.069000
         -00.200000+00.400000-00.062000
         -01.400000+00.300000-00.056000
         -02.500000+00.200000-00.052000
         -03.600000+00.100000-00.049000
         -04.800000+00.000000-00.046000
   8 —   -05.900000-00.100000-00.043000
         +02.650000+00.800000-00.133000          —  15°   4
         +01.400000+00.700000-00.129000
         +00.300000+00.600000-00.124500
         -00.450000+00.550000-00.122000
         -01.050000+00.500000-00.119000
         -01.400000+00.450000-00.117000
         -02.250000+00.400000-00.113500
         -02.850000+00.350000-00.110500
         -03.450000+00.300000-00.106500
         -04.050000+00.250000-00.102500
         -04.650000+00.200000-00.098000
         -05.800000+00.100000-00.088000
         -07.050000+00.000000-00.078500
  14 —   -08.200000-00.100000-00.070000
         +02.200000+00.900000-00.207000          —  20°   5
         +00.900000+00.800000-00.197000
           ADL        CLN         CHN
```

	ADL	CLN	CHN	δ	Curve No.	c_b/c	j
	-00.300000	+00.700000	-00.190000				
	-00.950000	+00.650000	-00.187000				
	-01.500000	+00.600000	-00.184000				
	-02.100000	+00.550000	-00.180000				
	-02.700000	+00.500000	-00.177000				
	-03.550000	+00.450000	-00.173500				
	-03.950000	+00.400000	-00.170000				
	-04.600000	+00.350000	-00.166500				
	-05.150000	+00.300000	-00.162500				
	-05.750000	+00.250000	-00.158500				
	-06.350000	+00.200000	-00.155000				
	-07.500000	+00.100000	-00.148500				
	-08.700000	+00.000000	-00.140500				
	-09.900000	-00.100000	-00.133000				
16	+01.900000	+01.000000	-00.247500	25°	6	0.15	1 (Cont'd)
	+00.700000	+00.900000	-00.245000				
	-00.550000	+00.800000	-00.242000				
	-01.750000	+00.700000	-00.238500				
	-02.300000	+00.650000	-00.237000				
	-02.900000	+00.600000	-00.235000				
	-03.560000	+00.550000	-00.233500				
	-04.150000	+00.500000	-00.231500				
	-04.700000	+00.450000	-00.229500				
	-05.300000	+00.400000	-00.227000				
	-05.850000	+00.350000	-00.225000				
	-06.400000	+00.300000	-00.222500				
	-07.000000	+00.250000	-00.220000				
	-07.500000	+00.200000	-00.217500				
	-08.650000	+00.100000	-00.212000				
	-09.800000	+00.000000	-00.205500				
	-10.900000	-00.100000	-00.198000				
17	+04.800000	+00.400000	+00.006000	0°	1	0.35	2
	+03.500000	+00.300000	+00.007000				
	+02.300000	+00.200000	+00.005000				
	+01.100000	+00.100000	+00.002000				
	+00.000000	+00.000000	+00.000000				
	-01.300000	-00.100000	-00.002000				
6	+02.100000	+00.400000	-00.011000	5°	2		
	+00.900000	+00.300000	-00.010000				
	+00.200000	+00.250000	-00.010000				
	-00.400000	+00.200000	-00.011000				
	-01.000000	+00.150000	-00.013000				
	-01.600000	+00.100000	-00.014000				
	-02.600000	+00.000000	-00.016000				
	-04.000000	-00.100000	-00.016000				
8	+01.950000	+00.600000	-00.042000	10°	3		
	+00.700000	+00.500000	-00.033500				
	+00.100000	+00.450000	-00.030500				
	-00.600000	+00.400000	-00.027500				
	-01.250000	+00.350000	-00.026000				
	-01.850000	+00.300000	-00.024500				
	-02.500000	+00.250000	-00.023000				
	-03.100000	+00.200000	-00.023000				
	-04.300000	+00.100000	-00.023000				
	-05.400000	+00.000000	-00.025000				

		δ	Curve No.	Cn/Ct	j
	-06.600000-00.100000-00.027000				
	+02.600000+00.800000-00.124000	15°	4	0.35	2 (Contd)
	+01.050000+00.700000-00.110500				
	-00.400000+00.600000-00.087000				
	-01.100000+00.550000-00.073000				
	-01.800000+00.500000-00.063000				
	-02.500000+00.450000-00.055000				
	-03.100000+00.400000-00.050000				
	-03.800000+00.350000-00.045500				
	-04.500000+00.300000-00.042000				
	-05.100000+00.250000-00.039000				
	-05.700000+00.200000-00.037500				
	-07.000000+00.100000-00.035000				
	-08.200000+00.000000-00.035000				
	-09.400000-00.100000-00.037000				
14	+01.500000+00.800000-00.190000	20°	5		
	+00.700000+00.700000-00.181000				
	-00.650000+00.650000-00.174000				
	-01.350000+00.600000-00.166000				
	-02.200000+00.550000-00.153500				
	-03.400000+00.500000-00.133500				
	-05.100000+00.450000-00.111000				
	-06.200000+00.400000-00.094000				
	-06.900000+00.350000-00.080000				
	-07.500000+00.300000-00.070000				
	-08.200000+00.250000-00.061000				
	-08.900000+00.200000-00.054000				
	-09.500000+00.150000-00.049000				
	-10.200000+00.100000-00.046000				
	-11.400000+00.000000-00.043000				
	-12.500000-00.100000-00.043000				
16	+01.300000+00.800000-00.200000	25°	6		
	+00.100000+00.700000-00.196000				
	-00.650000+00.650000-00.193500				
	-01.300000+00.600000-00.191000				
	-02.200000+00.550000-00.189000				
	-03.000000+00.500000-00.188000				
	-03.900000+00.450000-00.187000				
	-04.950000+00.400000-00.186000				
	-06.200000+00.350000-00.184000				
	-07.900000+00.300000-00.161000				
	-09.200000+00.250000-00.131000				
	-10.300000+00.200000-00.102000				
	-11.300000+00.150000-00.078000				
	-12.200000+00.100000-00.062500				
	-13.000000+00.050000-00.054000				
	-13.700000+00.000000-00.049500				
	-14.200000-00.100000-00.046000				
17	+05.200000+00.400000+00.017500	0°	1	0.50	3
	+03.850000+00.300000+00.016000				
	+02.550000+00.200000+00.011500				
	+01.300000+00.100000+00.006500				
	+00.000000+00.000000+00.000000				
	-01.300000-00.100000-00.005000				
6	+02.800000+00.500000+00.021500	5°	2		

ADL CLN CHN

	ADL	CLN	CHN	δ	Curve No.	C_b/C_t	j
	+01.450000	+00.400000	+00.020000				
	+00.200000	+00.300000	+00.016000				
	-01.100000	+00.200000	+00.010000				
	-02.400000	+00.100000	+00.003000				
	-03.600000	+00.000000	-00.005000				
	-04.800000	-00.100000	-00.009500				
7	+02.550000	+00.700000	+00.022500	10°	3	0.50	3 (Contd)
	+01.150000	+00.600000	+00.031000				
	-00.250000	+00.500000	+00.032000				
	-01.500000	+00.400000	+00.028000				
	-02.800000	+00.300000	+00.022000				
	-04.100000	+00.200000	+00.017000				
	-05.300000	+00.100000	+00.013000				
	-06.500000	+00.000000	+00.009500				
	-07.700000	-00.100000	+00.006500				
9	+02.800000	+00.900000	-00.052000	15°	4		
	+00.700000	+00.800000	+00.001500				
	-00.650000	+00.700000	+00.023000				
	-01.200000	+00.650000	+00.031500				
	-01.750000	+00.600000	+00.038000				
	-02.300000	+00.550000	+00.042500				
	-02.950000	+00.500000	+00.045000				
	-03.650000	+00.450000	+00.045500				
	-04.450000	+00.400000	+00.045000				
	-05.900000	+00.300000	+00.043000				
	-07.300000	+00.200000	+00.040000				
	-08.400000	+00.100000	+00.037000				
	-09.350000	+00.000000	+00.034000				
	-10.250000	-00.100000	+00.031000				
14	+02.650000	+00.800000	-00.130000	20°	5		
	+01.500000	+00.750000	-00.122000				
	+00.200000	+00.700000	-00.098000				
	-01.300000	+00.650000	-00.031000				
	-02.900000	+00.600000	-00.012000				
	-04.150000	+00.550000	-00.002000				
	-05.200000	+00.500000	+00.013000				
	-06.100000	+00.450000	+00.049000				
	-06.500000	+00.430000	+00.056000				
	-06.900000	+00.400000	+00.064000				
	-07.600000	+00.350000	+00.070500				
	-08.300000	+00.300000	+00.072000				
	-08.900000	+00.250000	+00.071500				
	-09.450000	+00.200000	+00.070000				
	-10.500000	+00.100000	+00.067000				
	-11.400000	+00.000000	+00.065000				
	-12.300000	-00.100000	+00.063000				
17	+03.300000	+00.800000	-00.160000	25°	6		
	+01.900000	+00.700000	-00.153000				
	+00.200000	+00.600000	-00.145600				
	-01.700000	+00.550000	-00.141000				
	-02.150000	+00.520000	-00.137600				
	-03.200000	+00.500000	-00.125000				
	-05.450000	+00.450000	-00.069000				
	-07.100000	+00.400000	-00.020000				
	-08.200000	+00.360000	+00.018000				

```
        ADL          CLN          CHN
   -09.600000+00.300000+00.028000
   -10.350000+00.260000+00.039000
   -11.300000+00.2[illegible]0000+00.086000
   -11.600000+00.180000+00.090500
   -12.100000+00.140000+00.094000
   -12.500000+00.100000+00.095000
   -13.450000+00.000000+00.093000
   -14.500000-00.100000+00.086500
17 END OF DATA
```